

# Chemistry

Victorian Certificate of Education Study Design

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Latoya BARTON  
*The sunset* (detail)  
from a series of twenty-four  
9.0 x 9.0 cm each, oil on board



Tarkan ERTURK  
*Visage* (detail)  
201.0 x 170.0 cm  
synthetic polymer paint, on cotton duck



Liana RASCHILLA  
*Teapot* from the *Crazy Alice* set  
19.0 x 22.0 x 22.0 cm  
earthenware, clear glaze, lustres



Nigel BROWN  
*Untitled physics* (detail)  
90.0 x 440.0 x 70.0 cm  
composition board, steel, loudspeakers,  
CD player, amplifier, glass



Kate WOOLLEY  
*Sarah* (detail)  
76.0 x 101.5 cm, oil on canvas



Chris ELLIS  
*Tranquility* (detail)  
35.0 x 22.5 cm  
gelatin silver photograph



Christian HART  
*Within without* (detail)  
digital film, 6 minutes



Kristian LUCAS  
*Me, myself, I and you* (detail)  
56.0 x 102.0 cm  
oil on canvas



Merryn ALLEN  
*Japanese illusions* (detail)  
centre back: 74.0 cm, waist (flat): 42.0 cm  
polyester cotton



Ping (Irene) VINCENT  
*Boxes* (detail)  
colour photograph



James ATKINS  
*Light cascades* (detail)  
three works, 32.0 x 32.0 x 5.0 cm each  
glass, fluorescent light, metal



Tim JOINER  
*14 seconds* (detail)  
digital film, 1.30 minutes



Lucy McNAMARA  
*Precariously* (detail)  
156.0 x 61.0 x 61.0 cm  
painted wood, oil paint, egg shells, glue, stainless steel wire

Accredited by the Victorian Qualifications Authority  
33 St Andrews Place, East Melbourne, Victoria 3002

Developed and published by the Victorian Curriculum and Assessment Authority  
41 St Andrews Place, East Melbourne, Victoria 3002

This completely revised and reaccredited edition published 2005.

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Edited by Ruth Learner  
Cover designed by Chris Waldron of BrandHouse  
Desktop published by Julie Coleman

Chemistry

ISBN 1 74010 301 7

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## **IMPORTANT INFORMATION**

### **Accreditation period**

Units 1–2: 2007–2011

Units 3–4: 2008–2011

The accreditation period for Units 1 and 2 commences on 1 January 2007.

The accreditation period for Units 3 and 4 commences on 1 January 2008.

### **Other sources of information**

The *VCAA Bulletin* is the only official source of changes to regulations and accredited studies. The *VCAA Bulletin*, including supplements, also regularly includes advice on VCE studies. It is the responsibility of each VCE teacher to refer to each issue of the *VCAA Bulletin*. The *VCAA Bulletin* is sent in hard copy to all VCE providers. It is available on the Victorian Curriculum and Assessment Authority's website at [www.vcaa.vic.edu.au](http://www.vcaa.vic.edu.au)

To assist teachers in assessing school-assessed coursework in Units 3 and 4, the Victorian Curriculum and Assessment Authority publishes an assessment handbook that includes advice on the assessment tasks and performance descriptors for assessment.

The current year's *VCE and VCAL Administrative Handbook* contains essential information on assessment and other procedures.

### **VCE providers**

Throughout this study design the term 'school' is intended to include both schools and other VCE providers.

# Introduction

## **RATIONALE**

Chemistry is a key science in explaining the workings of our universe through an understanding of the properties and interaction of substances that make up matter. Most processes, from the formation of molecules in outer space to the complex biological interactions occurring in cells, can be described by chemical theories. Although there are no sharp boundaries between sciences such as chemistry, physics and biology, chemistry is used to explain natural phenomena at the molecular level, as well as create new materials such as medicines and polymers.

The development of modern society has been intimately linked with the successful integration of chemical knowledge into new technologies. This continues with emerging fields such as biotechnology and nanotechnology.

There are many unanswered questions in science, and many unexplained phenomena such as the language of the brain and the evolution of climate. Over time, chemistry will play a key role in answering some of these questions as well as providing a sustainable environment for the future.

Studying Chemistry can enrich students' lives through the development of particular knowledge, skills and attitudes, and enable them to become scientifically capable members of society. It will also provide a window on what it means to be a scientific researcher, working as a member of a community of practice, including insight into how new ideas are developed and investigated, and how evidence or data collected is used to expand knowledge and understanding of chemistry.

Many people develop an 'applied' knowledge of chemistry through their careers and day-to-day pursuits. Chemistry permeates numerous fields of endeavour, including agriculture, art, biochemistry, dietetics, engineering, environmental studies, food, forensic science, forestry, horticulture, law, medicine, oceanography, pharmacy, sports science and winemaking.

The chemistry undertaken in this study is representative of the discipline and the major ideas of chemistry. Some students will develop a passion for chemistry and be inspired to pursue further studies. All students, however, should become more informed, responsible decision-making citizens, able to use chemical knowledge and scientific arguments in their everyday lives and to evaluate and debate important contemporary issues such as the future of our environment and its management.

## AIMS

This study is designed to enable students to:

- develop their understanding of the language, processes and major ideas of chemistry;
- understand the role of experimental evidence in developing and generating new ideas and knowledge in chemistry;
- understand the ways chemical knowledge is organised, challenged, revised and extended;
- assess the quality of assumptions and the limitations of models, data and conclusions;
- develop skills in the design and safe conduct of practical investigations including risk assessment, hazard identification and waste management;
- develop the skills and knowledge required to complete experimental processes and procedures and undertake research investigations;
- conduct practical investigations to collect, interpret, and analyse data and evidence, and present conclusions;
- develop skills in the effective communication of chemical ideas to a range of audiences;
- be aware of the ethics of scientific research that apply to investigations in chemistry;
- understand how chemistry relates to other areas of science and technology;
- be aware of the social, economic and environmental impacts of current and emerging areas of chemistry and associated technologies.

## STRUCTURE

The study is made up of four units.

Unit 1: The big ideas of chemistry

Unit 2: Environmental chemistry

Unit 3: Chemical pathways

Unit 4: Chemistry at work

Each unit deals with specific content and is designed to enable students to achieve a set of outcomes. Each outcome is described in terms of key knowledge and the key skills listed on page 12.

## ENTRY

There are no prerequisites for entry to Units 1, 2 and 3. Students must undertake Unit 3 prior to undertaking Unit 4. Students entering Unit 3 without Units 1 and/or 2 may be required to undertake additional reading as prescribed by their teacher. Units 1 to 4 are designed to a standard equivalent to the final two years of secondary education. All VCE studies are benchmarked against comparable national and international curriculum.

## DURATION

Each unit involves at least 50 hours of scheduled classroom instruction.

## CHANGES TO THE STUDY DESIGN

During its period of accreditation minor changes to the study will be notified in the *VCAA Bulletin*. The *VCAA Bulletin* is the only source of changes to regulations and accredited studies and it is the responsibility of each VCE teacher to monitor changes or advice about VCE studies published in the *VCAA Bulletin*.

## MONITORING FOR QUALITY

As part of ongoing monitoring and quality assurance, the Victorian Curriculum and Assessment Authority will periodically undertake an audit of Chemistry to ensure the study is being taught and assessed as accredited. The details of the audit procedures and requirements are published annually in the *VCE and VCAL Administrative Handbook*. Schools will be notified during the teaching year of schools and studies to be audited and the required material for submission.

## SAFETY

This study may involve the handling of potentially hazardous substances and/or the use of potentially hazardous equipment. It is the responsibility of the school to ensure that duty of care is exercised in relation to the health and safety of all students undertaking the study.

Students and teachers should observe appropriate safety precautions when undertaking practical work. Laboratory work should be supervised by the teacher. Laboratory standards and practices and the use of chemicals should be consistent with legal requirements and appropriate guidelines.

Students and teachers should consider Risk Assessment and Risk Management including Material Safety Data Sheets (MSDS) as part of practical activities and, in particular, the extended experimental investigation task.

## USE OF INFORMATION AND COMMUNICATIONS TECHNOLOGY

In designing courses for this study teachers should incorporate information and communications technology where appropriate and applicable to the teaching and learning activities. The Advice for Teachers section provides specific examples of how information and communications technology can be used in this study.

Datalogging, spreadsheets, modelling and simulation, Internet research and data exchanges are particularly suited to this study.

## KEY COMPETENCIES AND EMPLOYABILITY SKILLS

This study offers a number of opportunities for students to develop key competencies and employability skills. The Advice for Teachers section provides specific examples of how students can demonstrate key competencies during learning activities and assessment tasks.

## LEGISLATIVE COMPLIANCE

When collecting and using information, the provisions of privacy and copyright legislation, such as the Victorian *Information Privacy Act 2000* and *Health Records Act 2001*, and the federal *Privacy Act 1988* and *Copyright Act 1968* must be met.

# Assessment and reporting

## **SATISFACTORY COMPLETION**

The award of satisfactory completion for a unit is based on a decision that the student has demonstrated achievement of the set of outcomes specified for the unit. This decision will be based on the teacher's assessment of the student's performance on assessment tasks designated for the unit. Designated assessment tasks are provided in the details for each unit. The Victorian Curriculum and Assessment Authority publishes an assessment handbook that includes advice on the assessment tasks and performance descriptors for assessment for Units 3 and 4.

Teachers must develop courses that provide opportunities for students to demonstrate achievement of outcomes. Examples of learning activities are provided in the Advice for Teachers section.

Schools will report a result for each unit to the Victorian Curriculum and Assessment Authority as S (Satisfactory) or N (Not Satisfactory).

Completion of a unit will be reported on the Statement of Results issued by the Victorian Curriculum and Assessment Authority as S (Satisfactory) or N (Not Satisfactory). Schools may report additional information on levels of achievement.

## **AUTHENTICATION**

Work related to the outcomes will be accepted only if the teacher can attest that, to the best of their knowledge, all unacknowledged work is the student's own. Teachers need to refer to the current year's *VCE and VCAL Administrative Handbook* for authentication procedures.

## **LEVELS OF ACHIEVEMENT**

### **Units 1 and 2**

Procedures for the assessment of levels of achievement in Units 1 and 2 are a matter for school decision. Assessment of levels of achievement for these units will not be reported to the Victorian Curriculum and Assessment Authority. Schools may choose to report levels of achievement using grades, descriptive statements or other indicators.

### Units 3 and 4

The Victorian Curriculum and Assessment Authority will supervise the assessment of all students undertaking Units 3 and 4.

In the study of Chemistry the student's level of achievement will be determined by school-assessed coursework, a mid-year examination and an end-of-year examination. The Victorian Curriculum and Assessment Authority will report the student's level of performance on each assessment component as a grade from A+ to E or UG (ungraded). To receive a study score, students must achieve two or more graded assessments and receive S for both Units 3 and 4. The study score is reported on a scale of 0–50. It is a measure of how well the student performed in relation to all others who took the study. Teachers should refer to the current year's *VCE and VCAL Administrative Handbook* for details on graded assessment and calculation of the study score. Percentage contributions to the study score in Chemistry are as follows:

- Unit 3 school-assessed coursework: 17 per cent
- Unit 4 school-assessed coursework: 17 per cent
- Mid-year examination: 33 per cent
- End-of-year examination: 33 per cent

Details of the assessment program are described in the sections on Units 3 and 4 in this study design.

## Units 1–4: Key skills

In this study a set of key skills is considered essential to Chemistry. These skills apply across Units 1 to 4. In designing teaching and learning programs for each unit, teachers must ensure that students are given the opportunity to develop, use and apply these skills and to demonstrate them in a variety of contexts. As the complexity of key knowledge increases from Units 1 to 4, students should demonstrate the skills at a progressively higher level.

These skills include the ability to:

### **Investigate and inquire scientifically**

- work independently and collaboratively as required to develop and apply safe and responsible work practices when completing all practical investigations including the appropriate disposal of wastes;
- conduct investigations that include collecting, processing, recording and analysing qualitative and quantitative data; draw conclusions consistent with the question under investigation and the information collected; evaluate procedures and reliability of data;
- construct questions (and hypotheses); plan and/or design, and conduct investigations; identify and address possible sources of uncertainty;
- apply ethics of scientific research when conducting and reporting on investigations.

### **Apply chemical understandings**

- make connections between concepts; process information; apply understandings to familiar and new contexts;
- use first and second-hand data and evidence to demonstrate how chemical concepts and theories have developed and been modified over time;
- analyse issues and implications relating to scientific and technological developments;
- analyse and evaluate the reliability of chemistry related information and opinions presented in the public domain.

### **Communicate chemical information and understandings**

- interpret, explain and communicate chemical information and ideas accurately and effectively;
- use communication methods suitable for different audiences and purposes;
- use scientific language and conventions correctly, including chemical equations and units of measurement.

# Unit 1: The big ideas of chemistry

The story of chemistry begins with the building of the Periodic Table from speculation, debate and experimental evidence. The Periodic Table provides a unifying framework for studying the chemistry of the elements using their chemical and physical properties to locate their position. The electron configuration of an element, its tendency to form a particular bond type and its ability to behave as an oxidant or reductant can all be linked to its position in the Periodic Table.

A study of the development of our understanding about the internal structure of the atom illustrates to students the collaborative and step-by-step way in which scientific theories and models are formed.

Students study the models for metallic, ionic and covalent bonding. They consider the widespread use of polymers as an example of the importance of chemistry to their everyday lives. Students investigate the uses of materials and how these have changed. Examples could include improved corrosion prevention or limitation and carbon nanotubes and self-repairing materials.

Students are introduced to the development and application of 'smart' materials. Developing new materials has escalated with the use of synchrotron science that explores particle behaviour at an ever decreasing size. Some examples of new materials are alloys, fibres and compounds incorporating polymers, ceramics, biopolymers, films and coatings.

Students use the language of chemistry, its symbols and chemical formulas and equations, to explain observations and data collected from experiments.

## AREA OF STUDY 1

### The Periodic Table

This area of study focuses on the historical development of, and the relationship between, the Periodic Table and atomic theory. Students investigate trends and patterns within the Periodic Table and use subshell notation to describe the electronic configuration of elements. They explore the link between the electronic configuration of an element and the type of bonding in which it participates. Students are introduced to many of the major qualitative and quantitative ideas fundamental to chemistry including empirical and molecular formulas and the mole concept. They undertake practical activities that build their understanding of the Periodic Table.

### Outcome 1

On completion of this unit the student should be able to explain how evidence is used to develop or refine chemical ideas and knowledge.

To achieve this outcome the student will draw on key knowledge outlined in areas of study 1 and 2, and key skills listed on page 12.

*Key knowledge*

This knowledge includes

- The Periodic Table
  - historical development from Mendeleev to Seaborg
  - trends and patterns of properties within The Periodic Table: atomic number, types of compounds formed, metallic/non-metallic character, chemical reactivity of elements;
- atomic theory
  - historical development of the model of atomic theory with contributions from Dalton to Chadwick
  - limitations of the model of atomic theory
  - mass number, isotopes, calculation of relative atomic mass, electronic configuration including subshells;
- the mole concept including empirical and molecular formulas, percentage composition, Avogadro's constant;
- interpretation of data from mass spectrometry.

**AREA OF STUDY 2****Materials**

This area of study focuses on the structure, properties and applications of materials.

Students investigate how the bonding models were developed to explain the properties of materials. Students use these models to explain the properties and structure of metals, ionic compounds, and molecular, covalent network lattice and covalent layer lattice substances. They investigate the properties of alkanes and alkenes including isomers. Students examine the reactions that occur in addition polymerisation and the properties of addition polymers. They explore the role of surfaces in the applications of nanotechnology.

**Outcome 2**

On completion of this unit the student should be able to use models of structure and bonding to explain the properties and applications of materials.

To achieve this outcome the student will draw on key knowledge outlined in areas of study 1 and 2, and key skills listed on page 12.

*Key knowledge*

This knowledge includes

- models of bonding to explain observed properties including melting temperature, electrical conductivity, chemical reactivity, shape, polarity of bonds, intermolecular forces
  - metals
  - ionic compounds
  - molecular substances, network lattices, layer lattices;
- limitations of the bonding models;
- properties and systematic naming of alkanes and alkenes up to  $C_6$ ;
- structural isomers of  $C_4H_{10}$ ;
- behaviour of surfaces and the application of surface chemistry in nanotechnology;

- addition polymers
  - relationship between structure, properties and applications,
  - synthesis, cross-linking
  - development of customised polymers.

## ASSESSMENT

The award of satisfactory completion for a unit is based on a decision that the student has demonstrated achievement of the set of outcomes specified for the unit. This decision will be based on the teacher's assessment of the student's overall performance on assessment tasks designated for the unit.

The key knowledge listed for each outcome and the set of key skills listed on page 12 should be used as a guide to course design and the development of learning activities. The key knowledge and skills do not constitute a checklist and such an approach is not necessary or desirable for determining the achievement of outcomes. The elements of key knowledge and skills should not be assessed separately.

Assessment tasks must be a part of the regular teaching and learning program and must not unduly add to the workload associated with that program. They must be completed mainly in class and within a limited timeframe. Teachers should select a variety of assessment tasks for their assessment program to reflect the key knowledge and skills being assessed and to provide for different learning styles.

For this unit students are required to demonstrate achievement of two outcomes. As a set these outcomes encompass both areas of study.

As a guide, between 10 and 15 hours of class time should be devoted to student laboratory/practical work, including any work which is assessed. Students may work in pairs, small groups or individually.

Demonstration of achievement of Outcomes 1 and 2 must be based on the student's performance on a selection of assessment tasks. Where teachers allow students to choose between tasks they must ensure that the tasks they set are of comparable scope and demand. Assessment tasks for this unit are:

- An extended experimental investigation. This could be student designed and/or planned or teacher directed and would require between three and five hours of laboratory/practical work. Results could be presented in a variety of formats. Students should complete a Risk Assessment and Risk Management as part of this task. Students could work in small groups or individually.

Or

- A summary report including annotations of three practical activities. This task would require between three and five hours of laboratory time. The annotations would illustrate the links between the practical activities (for example, data, techniques, concepts, problems faced and recommendations for future practical activities). Teachers may provide students with prompts to assist them with the annotations.

If the extended experimental investigation is completed in Unit 1, the summary report including annotations of three practical activities must be completed in Unit 2. If the summary report including annotations of three practical activities is completed in Unit 1, the extended experimental investigation must be completed in Unit 2.

And

At least one of the following:

- a response to stimulus material in written, oral, visual, or multimedia format;
- an analysis of first and/or second-hand data using structured questions;
- a written, oral, visual, multimedia, or web page presentation of a new material/s, or new use/s of an existing material.

## Unit 2: Environmental chemistry

Living things on earth have evolved to use water and the gases of the atmosphere in the chemical reactions that sustain them. Water is used by both plants and animals to carry out their energy-producing reactions, dissolve their nutrients and transport their wastes. The atmosphere supplies life-giving gases, provides temperature that sustains life, and gives protection from harmful radiation.

Algae blooms, salinity, acid rain, depletion of ozone, photochemical smog, and global warming continue to have an impact on living things and the environment. Students will investigate how chemistry is used to respond to the effects of human activities on our environment.

Typical tasks of environmental chemists include monitoring the concentration of wastes in the effluent from an industrial plant and monitoring air quality. Quantitative chemical calculations play an essential role in these tasks and students are introduced to the types of calculations used every day by analytical chemists.

The principles and applications of green chemistry – benign by design – to processes and practices are included. The goal of these processes is to achieve hazard-free, waste-free, energy efficient synthesis of non-toxic products whilst maintaining efficiency. Students are introduced to new, cleaner and more efficient chemical processes that have been designed using green chemistry principles.

Students continue to use and develop the language of chemistry, its symbols and chemical formulas and equations, to explain observations and data collected from experiments.

### AREA OF STUDY 1

#### Water

This area of study focuses on the study of water. Students explore the special properties (chemical and physical) of water which make it so important to living things and relate the properties to chemical bonding characteristics. Students investigate chemical reactions that take place in aqueous solution by conducting practical activities on precipitation, acid-base reactions and redox reactions such as corrosion. They use full and ionic equations to represent the reactions and calculate the amount of reactants and products involved.

Students investigate the concepts of solubility, concentration and pH, when dealing with problems of pollution and maintaining the quality of water. They investigate at least one process that uses the principles of green chemistry.

**Outcome 1**

On completion of this unit the student should be able to write balanced equations and apply these to qualitative and quantitative investigations of reactions involving acids and bases, the formation of precipitates and gases, and oxidants and reductants.

To achieve this outcome the student will draw on key knowledge outlined in areas of study 1 and 2, and key skills listed on page 12.

**Key knowledge**

This knowledge includes

- role of water in maintaining life in the environment
  - unique properties of water: relationship between structure and bonding, and properties and uses including solubility and conductivity
  - ways in which substances behave in water: the dissociation of soluble ionic solutes; the ionisation of polar molecules such as acids; the separation of non-ionising polar molecules such as ethanol
  - maintaining water quality: solubility, precipitation reactions, pH
  - desalination, including the principles of distillation;
- acids and bases: proton transfer; common reactions of acids; strong and weak acids and bases; polyprotic acids; amphoteric substances;
- calculations including mass-mass stoichiometry and concentration and volume of solutions; pH of strong acids and of strong bases;
- redox reactions in aqueous solution including writing balanced equations for oxidation and reduction reactions, for example metal displacement reactions, corrosion of iron;
- application of the principles of green chemistry; for example, replacement of halogenated solvents with supercritical carbon dioxide in industrial processes or in plant crop protection.

**AREA OF STUDY 2****The atmosphere**

This area of study focuses on the interaction between living things and gases of the atmosphere. Students use the kinetic molecular theory to explain and predict the behaviour of gases. They perform calculations using the gas laws. Students investigate the vital roles of oxygen, carbon dioxide and nitrogen through studies of the carbon and nitrogen cycles. They prepare and test the properties of one of these gases in the laboratory. Students explore state, national and global issues associated with the impact of human activities on the atmosphere.

**Outcome 2**

On completion of this unit the student should be able to explain how chemical reactions and processes occurring in the atmosphere help to sustain life on earth.

To achieve this outcome the student will draw on key knowledge outlined in areas of study 1 and 2, and key skills listed on page 12.

### Key knowledge

This knowledge includes

- role of the atmosphere in maintaining life in the environment
  - effects of human activities, such as agriculture, industry, transport, energy production, on the atmosphere
  - chemical reactions and processes of acid rain
  - qualitative effects of ozone depletion and photochemical smog
  - role of the carbon and nitrogen cycles in maintaining life on earth
  - the laboratory and industrial preparation of one gas of significance to the quality of the atmosphere;
- the major contributing gases to the enhanced greenhouse effect and at least one of the associated local, state, national or international protocols;
- kinetic molecular theory and its use in explaining properties of gases;
- calculations including those involving gas laws, molar volume ( $V_M$ ) at STP and SLC, the General Gas Equation, volume-volume and mass-volume stoichiometry.

### ASSESSMENT

The award of satisfactory completion for a unit is based on a decision that the student has demonstrated achievement of the set of outcomes specified for the unit. This decision will be based on the teacher's assessment of the student's overall performance on assessment tasks designated for the unit.

The key knowledge listed for each outcome and the set of key skills listed on page 12 should be used as a guide to course design and the development of learning activities. The key knowledge and skills do not constitute a checklist and such an approach is not necessary or desirable for determining the achievement of outcomes. The elements of key knowledge and skills should not be assessed separately.

Assessment tasks must be a part of the regular teaching and learning program and must not unduly add to the workload associated with that program. They must be completed mainly in class and within a limited timeframe. Teachers should select a variety of assessment tasks for their assessment program to reflect the key knowledge and skills being assessed and to provide for different learning styles.

For this unit students are required to demonstrate achievement of two outcomes. As a set these outcomes encompass both areas of study.

As a guide, between 10 and 15 hours of class time should be devoted to student laboratory/practical work, including any work which is assessed. Students may work in pairs, small groups or individually.

Demonstration of achievement of Outcomes 1 and 2 must be based on the student's performance on a selection of assessment tasks. Where teachers allow students to choose between tasks they must ensure that the tasks they set are of comparable scope and demand. Assessment tasks for this unit are:

- An extended experimental investigation. This could be student designed and/or planned or teacher directed and would require between three and five hours of laboratory/practical work. Results could be presented in a variety of formats. Students should complete a Risk Assessment and Risk Management as part of this task. Students could work in pairs, small groups or individually.

Or

- A summary report including annotations of three practical activities. This task would require between three and five hours of laboratory time. The annotations would illustrate the links between the practical activities (for example, data, techniques, concepts, problems faced and recommendations for future practical activities). Teachers may decide to provide students with prompts to assist them with the annotations.

If the extended experimental investigation is completed in Unit 1, the summary report including annotations of three practical activities must be completed in Unit 2. If the summary report including annotations of three practical activities is completed in Unit 1, the extended experimental investigation must be completed in Unit 2.

And

At least one of the following:

- a response to stimulus material in written, oral, visual, or multimedia format;
- an analysis of first and/or second-hand data using structured questions;
- a written, oral, annotated, visual, multimedia, or web page presentation related to green chemistry.

## Unit 3: Chemical pathways

In this unit students investigate the scope of techniques available to the analytical chemist. Chemical analysis is vital in the work of the forensic scientist, the quality control chemist at a food manufacturing plant, the geologist in the field, and the environmental chemist monitoring the health of a waterway.

Each technique of analysis depends on a particular property or reaction of the chemical being investigated. Consequently, an understanding of the chemistry is necessary in learning how and why the techniques work. Some techniques of analysis have been refined over many years to make them quicker and more accurate. Other techniques are now used in combination to provide higher and more reliable levels of accuracy, for example gas chromatography and mass spectrometry. State of the art analytical tools such as the Australian synchrotron will enable investigation of the properties of materials and chemical reactions at the micro level.

Students investigate organic reaction pathways and the chemistry of particular organic molecules. A detailed knowledge of the structure and bonding of organic chemicals is important to the work of the synthetic organic chemist. In the wake of the work done on the genome project, synthesis of new medicines is one of the growth industries for the coming decades. Students investigate the role of organic molecules in the generation of biochemical fuels and forensic analysis.

Students will continue to investigate the application of principles of green chemistry to chemical processes and use the language and symbols of chemistry, and chemical formulas and equations to explain observations and data collected from experiments.

Students complete an extended experimental investigation drawn from area of study 1 or area of study 2.

### AREA OF STUDY 1

#### Chemical analysis

In this area of study students use a variety of analytical techniques to analyse products in the laboratory. They conduct volumetric analyses using acid-base and redox titrations and standard solutions, and carry out gravimetric analyses. They are also introduced to instrumental analytical techniques of spectroscopy and chromatography. Students review and apply their understanding of stoichiometry as they complete calculations related to their practical investigations. Students relate the operation of the analytical techniques and instruments to the chemical reactions and the chemical structures of the materials which are being analysed.

**Outcome 1**

On completion of this unit the student should be able to evaluate the suitability of techniques and instruments used in chemical analyses.

To achieve this outcome the student will draw on key knowledge outlined in area of study 1 and key skills listed on page 12.

**Key knowledge**

This knowledge includes

- volumetric analysis: simple and back titrations, acid-base and redox titrations;
- gravimetric analysis;
- calculations including amount of solids, liquids and gases; concentration; volume, pressure and temperature of gases;
- use of oxidation numbers to write redox equations;
- principles and applications of chromatographic techniques and interpretation of qualitative and quantitative data from thin layer chromatography (TLC), high performance liquid chromatography (HPLC) and gas chromatography (GC);
- principles and applications of spectroscopic techniques and interpretation of qualitative and quantitative data from atomic absorption spectroscopy (AAS), infrared spectroscopy (IR), mass spectroscopy, nuclear magnetic resonance spectroscopy (NMR), and visible and ultraviolet spectroscopy (visible-UV);
- matching analytical technique/s to a particular task.

**AREA OF STUDY 2****Organic chemical pathways**

In this area of study students investigate systematic organic chemistry including production of starting materials for particular reaction pathways. Students use molecular models and conduct simple laboratory investigations to observe the properties and reactions of different homologous series and functional groups. Students investigate the use of biochemical fuels. They design reaction pathways to prepare organic compounds from given starting materials.

Students investigate how forensic analysis relies on the use of organic chemicals (including DNA) and the role of organic chemicals (including proteins) in the development of medicines.

**Outcome 2**

On completion of this unit the student should be able to identify and explain the role of functional groups in organic reactions and construct reaction pathways using organic molecules.

To achieve this outcome the student will draw on key knowledge outlined in area of study 2 and key skills listed on page 12.

**Key knowledge**

This knowledge includes

- structure and systematic nomenclature of alkanes, alkenes, amines, chloroalkanes, alkanols and carboxylic acids up to  $C_{10}$ ;
- common reactions of organic compounds: addition reactions of alkenes, substitution reactions of alkanes and primary chloroalkanes, oxidation of primary alkanols, esterification;

- organic reaction pathways including the production of esters from alkenes, condensation and polymerisation reactions that produce large biomolecules;
- primary, secondary and tertiary structure of proteins and the function of protein catalysts (enzymes);
- biochemical fuels including fermentation of sugars to produce ethanol;
- the structure and bonding of DNA and its applications in forensic analysis;
- use of proteins as markers for disease;
- function of organic molecules in the design and synthesis of medicines including the production of aspirin from salicylic acid.

## ASSESSMENT

The award of satisfactory completion for a unit is based on a decision that the student has demonstrated achievement of the set of outcomes specified for the unit. This decision will be based on the teacher's assessment of the student's overall performance on assessment tasks designated for the unit. The Victorian Curriculum and Assessment Authority publishes an assessment handbook that includes advice on the assessment tasks and performance descriptors for assessment.

The key knowledge listed for each outcome and the set of key skills listed on page 12 should be used as a guide to course design and the development of learning activities. The key knowledge and skills do not constitute a checklist and such an approach is not necessary or desirable for determining the achievement of outcomes. The elements of key knowledge and skills should not be assessed separately.

### Assessment of levels of achievement

The student's level of achievement in Unit 3 will be determined by school-assessed coursework and a mid-year examination.

#### *Contribution to final assessment*

School-assessed coursework for Unit 3 will contribute 17 per cent to the study score.

The level of achievement for Unit 3 is also assessed by a mid-year examination, which will contribute 33 per cent to the study score.

### **School-assessed coursework**

Teachers will provide to the Victorian Curriculum and Assessment Authority a score representing an assessment of the student's level of achievement.

The score must be based on the teacher's rating of performance of each student on the tasks set out in the following table and in accordance with an assessment handbook published by the Victorian Curriculum and Assessment Authority. The assessment handbook also includes advice on the assessment tasks and performance descriptors for assessment.

Assessment tasks must be a part of the regular teaching and learning program and must not unduly add to the workload associated with that program. They must be completed mainly in class and within a limited timeframe. Where optional assessment tasks are used, teachers must ensure that they are comparable in scope and demand. Teachers should select a variety of assessment tasks for their program to reflect the key knowledge and skills being assessed and to provide for different learning styles.

School-assessed coursework in Chemistry includes assessment of laboratory/practical work. As a guide, between 10 and 15 hours of class time should be devoted to student laboratory/practical work. Students should maintain records of their work.

The extended experimental investigation could be student designed and/or planned or teacher directed and would require between three and five hours of practical work. Students could work in pairs or small groups but must present the results individually. Students should complete a Risk Assessment and Risk Management as part of this task. Results could be presented in a variety of formats.

Outcomes	Marks allocated*	Assessment tasks
<b>Outcome 1</b> Evaluate the suitability of techniques and instruments used in chemical analyses.	50	An extended experimental investigation that can be drawn from either area of study 1 or area of study 2.  <b>AND</b> <b>From the area of study NOT used for the extended experimental investigation</b>
<b>Outcome 2</b> Identify and explain the role of functional groups in organic reactions and construct reaction pathways using organic molecules.	25	A written report of one practical activity.  <b>AND</b> One task selected from the following: <ul style="list-style-type: none"> <li>• a response to stimulus material in written, oral or visual format</li> <li>• an analysis of first or second-hand data using structured questions</li> <li>• a report in written, oral, multimedia or visual format related to chemical pathways.</li> </ul>
	25	
<b>Total marks</b>	<b>100</b>	

\*School-assessed coursework for Unit 3 contributes 17 per cent to the study score.

### Mid-year examination

The examination will be set by a panel appointed by the Victorian Curriculum and Assessment Authority.

### Description

Students will answer a series of questions set by an examination panel.

All key knowledge that underpins the outcomes in Unit 3 and the set of key skills listed on page 12 are examinable.

Outcomes 1 and 2 will contribute approximately equally to the examination.

### Format

The examination will consist of two sections: Section A multiple-choice items and Section B short-answer items.

### Conditions

The examination will be completed under the following conditions:

- Duration: one and a half hours.
- Date: mid-year, on a date to be published annually by the Victorian Curriculum and Assessment Authority.

- Victorian Curriculum and Assessment Authority examination rules will apply. Details of these rules are published annually in the *VCE and VCAL Administrative Handbook*.
- The examination will be marked by a panel appointed by the Victorian Curriculum and Assessment Authority.

**Contribution to final assessment**

The examination will contribute 33 per cent to the study score.

## Unit 4: Chemistry at work

In this unit students investigate the industrial production of chemicals and the energy changes associated with chemical reactions.

Chemical reactions produce a diverse range of products we use and depend on every day. Access to large quantities of raw materials and reliable energy supplies for these reactions is necessary to maintain continuous production of high quality useful chemicals. Features that affect chemical reactions such as the rate and yield or equilibrium position are investigated. Students explore how an understanding of these features is used to obtain optimum conditions in the industrial production of a selected chemical.

Our society uses a range of energy sources, including coal to generate electricity and gas for heating, oil for transport, and solar and wind for small and large scale production of electricity. Students investigate how energy is produced from available resources and consider the efficiencies, advantages and disadvantages of each energy resource.

Galvanic cells and electrolytic cells operate by transforming chemical and electrical energy. Students investigate their operating principles, both in the laboratory and in important commercial and industrial applications including fuel cells. These cells are used in smaller appliances such as mobile phones, CD players, personal computers, and in larger scale systems such as cars and motor bikes, and in the production of chemicals.

Students will continue to investigate the application of principles of green chemistry to chemical processes and use the language and symbols of chemistry, and chemical formulas and equations to explain observations and data collected from experiments.

### AREA OF STUDY 1

#### Industrial chemistry

This area of study focuses on the factors that affect the rate and extent of a chemical reaction. Students study energy profiles and how equilibrium law is applied to homogeneous equilibria. They conduct experiments to investigate the effect of temperature, concentration of reagents, pressure and catalysts on the position of equilibrium of a reaction, and apply Le Chatelier's Principle to explain their results.

Students explore how factors affecting rate and equilibrium are applied to achieve the optimum reaction conditions in the industrial production of chemicals.

One chemical selected from ammonia, ethene, sulfuric acid or nitric acid is studied in detail.

**Outcome 1**

On completion of this unit the student should be able to analyse the factors that determine the optimum conditions used in the industrial production of the selected chemical.

To achieve this outcome the student will draw on key knowledge outlined in area of study 1 and key skills listed on page 12.

*Key knowledge*

This knowledge includes

- collision theory and factors that affect the rate of a reaction including activation energy;
- energy profile diagrams and the use of  $\Delta H$  notation;
- reversible reactions: homogeneous equilibria and the equilibrium law, Le Chatelier's Principle and factors which affect the position of equilibrium;
- pH as a measure of strength of acids and bases;  $K_w$ ,  $K_a$  for weak acids;
- principles of waste management used in the chemical industry;
- the industrial production of the selected chemical
  - factors affecting the production including rate and equilibrium position, catalysts, temperature, pressure
  - waste management including generation, treatment and reduction
  - health and safety
  - uses of the selected chemical.

**AREA OF STUDY 2****Supplying and using energy**

This area of study focuses on use of different energy resources. Students evaluate the extent of the reserves of some of these resources, how each resource is used and the advantages and disadvantages of their continued use. Students conduct experiments using calorimeters to measure the energy of chemical reactions.

The electrochemical series is a useful tool in the prediction of redox reactions in aqueous solution. Students construct and operate simple galvanic and electrolytic cells and use the electrochemical series to predict and explain their results. They extend their study of stoichiometry with the application of Faraday's laws to solve problems involving quantitative calculations for electrolysis reactions.

**Outcome 2**

On completion of this unit the student should be able to analyse chemical and energy transformations occurring in chemical reactions.

To achieve this outcome the student will draw on key knowledge outlined in area of study 2 and key skills listed on page 12.

*Key knowledge*

This knowledge includes

- comparison of energy sources: types, uses and sustainability of sources including brown coal, natural gas, nuclear fission and biochemical fuels;
- application of calorimetry to measure energy changes in chemical reactions in solution calorimetry and bomb calorimetry;

- use of the electrochemical series in predicting the products of redox reactions and writing half equations;
- limitations of predictions made using the electrochemical series;
- the construction and operation of simple galvanic primary and secondary cells;
- the construction and operation of fuel cells: advantages and disadvantages of fuel cells compared to conventional energy sources;
- the construction and operation of simple electrolytic cells: comparison of electrolytic cells;
- application of Faraday's laws in electrochemistry.

## ASSESSMENT

The award of satisfactory completion for a unit is based on a decision that the student has demonstrated achievement of the set of outcomes specified for the unit. This decision will be based on the teacher's assessment of the student's overall performance on assessment tasks designated for the unit. The Victorian Curriculum and Assessment Authority publishes an assessment handbook that includes advice on the assessment tasks and performance descriptors for assessment.

The key knowledge listed for each outcome and the set of skills listed on page 12 should be used as a guide to course design and the development of learning activities. The key knowledge and skills do not constitute a checklist and such an approach is not necessary or desirable for determining the achievement of outcomes. The elements of key knowledge and skills should not be assessed separately.

### Assessment of levels of achievement

The student's level of achievement for Unit 4 will be determined by school-assessed coursework and an end-of-year examination.

#### *Contribution to final assessment*

School-assessed coursework for Unit 4 will contribute 17 per cent to the study score.

The level of achievement for Unit 4 is also assessed by an end-of-year examination, which will contribute 33 per cent to the study score.

### **School-assessed coursework**

Teachers will provide to the Victorian Curriculum and Assessment Authority a score representing an assessment of the student's level of achievement.

The score must be based on the teacher's rating of performance of each student on the tasks set out in the following table and in accordance with an assessment handbook published by the Victorian Curriculum and Assessment Authority. The assessment handbook also includes advice on the assessment tasks and performance descriptors for assessment.

Assessment tasks must be a part of the regular teaching and learning program and must not unduly add to the workload associated with that program. They must be completed mainly in class and within a limited timeframe. Where optional assessment tasks are used, teachers must ensure that they are comparable in scope and demand. Teachers should select a variety of assessment tasks for their program to reflect the key knowledge and skills being assessed and to provide for different learning styles.

School-assessed coursework in Chemistry includes assessment of laboratory/practical work. As a guide, between 10 and 15 hours of class time should be devoted to student laboratory/practical work. Students should maintain records of their work.

The summary report including annotations of three practical activities would require between three and five hours of practical work. The annotations would illustrate the links between the practical activities (for example, data, techniques, concepts, problems faced and recommendations for future practical activities). Teachers may provide students with prompts to assist them with the annotations.

Outcomes	Marks allocated*	Assessment tasks
<b>Outcome 1</b> Analyse the factors that determine the optimum conditions used in the industrial production of the selected chemical.	50	A summary report including annotations of three practical activities drawn from either area of study 1 and area of study 2.  <b>AND</b> <b>From the area of study NOT used for the summary report</b>
<b>Outcome 2</b> Analyse chemical and energy transformations occurring in chemical reactions.	25	A written report of one practical activity.  <b>AND</b> One task selected from the following: <ul style="list-style-type: none"> <li>• a response to stimulus material in written, oral or visual format</li> <li>• an analysis of first or second-hand data using structured questions</li> <li>• a report in written, oral, multimedia or visual format related to chemistry at work.</li> </ul>
	25	
<b>Total marks</b>	<b>100</b>	

\*School-assessed coursework for Unit 4 contributes 17 per cent to the study score.

### **End-of-year examination**

The examination will be set by a panel appointed by the Victorian Curriculum and Assessment Authority.

### **Description**

Students will answer a series of questions set by an examination panel.

All key knowledge that underpins the outcomes in Unit 4 and the set of key skills listed on page 12 are examinable.

Outcomes 1 and 2 will contribute approximately equally to the examination.

### **Format**

The examination will consist of two sections: Section A multiple-choice items and Section B short-answer items.

**Conditions**

The examination will be completed under the following conditions:

- Duration: one and a half hours.
- Date: end-of-year, on a date to be published annually by the Victorian Curriculum and Assessment Authority.
- Victorian Curriculum and Assessment Authority examination rules will apply. Details of these rules are published annually in the *VCE and VCAL Administrative Handbook*.
- The examination will be marked by a panel appointed by the Victorian Curriculum and Assessment Authority.

**Contribution to final assessment**

The examination will contribute 33 per cent to the study score.

## GLOSSARY

For the purposes of this study design the following definitions will apply.

Term	Definition
Ampholyte	Amphoteric electrolyte. The Ampholyte is an ionic species able to act as both an acid and base.
Avogadro's constant	$6.02 \times 10^{23} \text{ mol}^{-1}$ (1 mole contains $6.02 \times 10^{23}$ particles)
Biomolecules	A biomolecule is a chemical compound that naturally occurs in living organisms. Biomolecules consist primarily of carbon and hydrogen, along with nitrogen, oxygen, phosphorus and sulfur. Sometimes other elements are incorporated but these are much less common. Large molecules (often with repeating units) with specific biological functions including carbohydrates, proteins, lipids.
Customised polymers	Customised polymers are polymers designed and manufactured for a particular task or application.
Faraday's constant	$1F = 96500 \text{ C mol}^{-1}$
Gas constant R	$8.31 \text{ J K}^{-1} \text{ mol}^{-1}$
Green chemistry	Green chemistry is the design of chemical products and processes that reduce or eliminate the use and generation of hazardous substances. Whereas environmental chemistry is the chemistry of the natural environment, and of pollutant chemicals in nature, green chemistry seeks to reduce and prevent pollution at source.
Molar Volume ( $V_M$ ) is taken at Standard Laboratory Conditions (SLC)	$24.5 \text{ L mol}^{-1}$
Molar Volume ( $V_M$ ) is taken at Standard Temperature and Pressure (STP)	$22.4 \text{ L mol}^{-1}$
Nanotechnology	<p>Nanotechnology is the creation of materials, devices, and systems through the manipulation of individual atoms and molecules.</p> <p>Technology development at the atomic, molecular, or macromolecular range of approximately 1–100 nanometers to create and use structures, devices, and systems that have novel properties.</p>
Numbering of groups within the Periodic Table	Groups numbered 1–18 where group 1 = I, 2 = II, 13 = III, 14 = IV, 15 = V, 16 = VI, 17 = VII, 18 = VIII
One part per million or ppm	$1 \text{ mg L}^{-1}$

Term	Definition
Risk Management	<p>The Risk Management process involves identification of hazards, assessment of risks, control of risks and review and evaluation of control measures. Students conducting a risk assessment would use relevant Material Safety Data Sheets (MSDS) and:</p> <ul style="list-style-type: none"><li>• identify the hazards (hazardous or dangerous chemicals used or produced and important routes of entry for hazardous or dangerous chemicals)</li><li>• assess the risk (the way in which the chemical will be used)</li><li>• control the risk (procedures and equipment used to minimise risk and safe, responsible disposal of the chemical).</li></ul>
Systematic nomenclature	<p>Alkanols will be used to describe molecules that contain the hydroxyl (OH) group (previously known as alcohols). International Union of Pure and Applied Chemistry (IUPAC) naming system will be used to name organic chemicals.</p>
Units of concentration	$\text{mol L}^{-1}$
Units of pressure	$1 \text{ atm} = 101325 \text{ Pa} = 760 \text{ mmHg}$
Units of volume	$1 \text{ L} = 1000 \text{ mL}$

# Advice for teachers

## DEVELOPING A COURSE

A course outlines the nature and sequence of teaching and learning necessary for students to demonstrate achievement of the set of outcomes for a unit. The areas of study describe the learning context and the knowledge required for the demonstration of each outcome. Outcomes are introduced by summary statements and are followed by the key knowledge and skills which relate to the outcomes.

The key knowledge outlined in the areas of study is an indication of the content knowledge and conceptual understandings which should be covered by a course. The sequence of teaching an area of study is not necessarily prescribed by the sequence of the listed content.

A set of key skills listed on page 12 is common to each of the units. The opportunity to develop, use and apply the key skills should be integrated into the teaching sequence through the inclusion of appropriate learning activities, including practical work. The full set of key skills is integral to all units. The full set of key skills does not need to be covered by each activity nor each of the areas of study within a unit. As the complexity of key knowledge increases over Units 1 to 4, students should develop the key skills to a progressively higher level.

Teachers must develop courses that include appropriate learning activities to enable students to develop the knowledge and skills identified in the outcome statements in each unit. As student learning can be most effective when concepts are presented in a context that is relevant to the students, the designed programs should be contextually based. Teachers are encouraged to explore resources that would enrich the course, covering the emerging areas of science and the pervasive use of chemicals in the community, and the resulting issues relating to chemistry.

Laboratory activities are essential in developing an understanding of chemical concepts and to develop many of the key skills. Laboratory activities should be devised to explore and illustrate aspects of the outcomes for each area of study. Such activities can be very brief, to illustrate a particular concept or develop a specific skill, or they can be extended to cover a number of aspects of an outcome. It is anticipated that laboratory activities occupy at least 10 hours of class time for each unit and should not be restricted to those activities required for assessment of the unit.

For Units 1 and 2, teachers must select assessment tasks from the list provided. A range of tasks should be selected in order to assess appropriately different knowledge and skills and to cater for different learning styles. Tasks do not have to be lengthy to make a decision about student demonstration of achievement of an outcome.

In Units 3 and 4, assessment is more structured. For some outcomes, or aspects of an outcome, the assessment tasks are prescribed. The contribution that each outcome makes to the total score for school-assessed coursework is also stipulated.

When designing a course, teachers should ensure that they give students the opportunity to develop and demonstrate their knowledge, understanding and mastery of skills in a variety of ways. Suitable learning activities include experimenting, constructing models, researching, using web-based learning modules, making a wall poster, responding to a published feature article, preparing an annotated flowchart for a sequence of events, responding to key questions, writing an account of a particular process, preparing and presenting a short report, explaining the concepts seen in a video or documentary.

In the study concepts are introduced and then revisited at a greater level of complexity in subsequent units. Throughout the four units, the key ideas of structure, reactions and energy are developed in a variety of contexts and at an increasing level of sophistication. The tools chemists use to obtain evidence, and how this evidence is used to propose models and refine chemical knowledge, also forms a common thread. The learning activities designed for each unit should reflect the progressively increased level of complexity of chemical ideas.

The matrix below gives some examples of how these key ideas are revisited from unit to unit.

Unit	Structure and bonding	Reactions	Energy	Skills chemists use
1	Atomic structure Metallic structure Ionic lattice Structure of covalent compounds, molecular structure and covalent lattice structures Structure of alkanes and alkenes Isomers Surface structures Structure of addition polymer	Reactivity trends in the Periodic Table Reactions of metals, ionic and molecular substances Reactions of alkanes and alkenes Surface reactions Addition polymerisation reactions	Ionisation energy Interactions between charged particles Electrostatic nature of chemical bonding Energy from combustion of alkanes Energy and change of state	Collection of experimental data Observation skills Laboratory techniques Data management and interpretation skills
2	Structure of the water molecule Polar molecules Structure of states of matter Structural changes that accompany change of states	Dissociation and ionisation reactions in water Reaction of solutes in solvents Reactions of acids and bases Redox reactions Reactions in the atmosphere that result from human activity Acid rain, ozone depletion, photochemical smog	Special properties of water; latent and specific heat Kinetic molecular theory Reactions driven by solar energy, e.g. ozone depletion, photochemical smog, greenhouse effect	Communication skills Calculations Information and communications technology skills Modelling

Unit	Structure and bonding	Reactions	Energy	Skills chemists use
3	Dependence of instrumental analytical techniques on structure Interaction of electromagnetic radiation with structure and application to instrumental analysis Structure of organic compounds Structural changes in organic reaction pathways Primary, secondary and tertiary structure of proteins Dependence of enzyme action on structure Structure of DNA Structural changes in the synthesis of medicines	Use of chemical reaction in chemical analysis, e.g. acid/base, redox, precipitation Reactions of organic compounds Addition reactions of alkenes Substitution reactions of alkanes Esterification reactions Condensation polymerisation reactions Function of enzymes and catalysts Production of biochemical fuels Synthesis of medicines	Energies of electromagnetic radiation Combustion reactions of alkanes Production of fuels from fractional distillation of crude oil Production and use of biochemical fuels	Collection of experimental data Observation skills Laboratory techniques Data management and interpretation skills Communication skills Calculations Information and communications technology skills Modelling
4	Collision theory Structures of acids and bases Relationship between structure of chemicals and their industrial production	Collision theory Reversible reactions and equilibrium Ionisation of acids and bases Industrial production of selected chemicals Exothermic and endothermic reactions Redox reactions including reactions in galvanic fuel and electrolytic cells Faraday's laws	Activation energy and rates of reaction Heats of reaction Energy profile diagrams Calorimetry Comparison of energy sources Galvanic cells: primary and secondary cells Fuel cells Electrolytic cells	

This outline is not meant to be prescriptive or exhaustive, although key knowledge areas could represent a teaching sequence.

### USE OF INFORMATION AND COMMUNICATIONS TECHNOLOGY

In designing courses and developing learning activities for Chemistry, teachers should make use of applications of information and communications technology and learning technologies, such as computer-based learning, multimedia and the World Wide Web, where appropriate and applicable to teaching and learning activities.

Data logging can be used in investigations that require taking measurements in the short or long term such as monitoring changes in pH or temperature in the course of chemical reactions.

Computer programs are available which demonstrate the three-dimensional shapes of molecules and simulate such concepts as chemical equilibrium.

Information and communications technology can also be a valuable tool in helping students develop many of the key communication skills required of a chemist. Electronic spreadsheets and graphing can be used to represent first-hand or second-hand data. In this form, data can then be manipulated easily for subsequent analysis, interpretation and evaluation.


## KEY COMPETENCIES AND EMPLOYABILITY SKILLS

Students undertaking the following types of assessment, in addition to demonstrating their understanding and mastery of the content of the study, typically demonstrate the following key competencies and employability skills.

Assessment task	Key competencies and employability skills
<b>Summary report of practical investigations</b>	Planning, organisation and (written) communication
<b>Extended practical investigation</b>	Self management, teamwork, problem solving, initiative, enterprise, communication
<b>Response to stimulus material</b>	Interpreting information
<b>Presentation (oral/written)</b>	Planning, organisation, collecting, interpreting and summarising information, communication
<b>Presentation (oral/written) using multimedia format</b>	Planning, organisation, collecting, interpreting and summarising information, communication, use of information and communications technology
<b>Analysis of information</b>	Problem-solving, interpreting information and organisation, (written) communication, self management

In completing work for this study, students may also demonstrate other key competencies and employability skills, such as working with others and in teams, and using mathematical ideas and techniques.

## LEARNING ACTIVITIES

Examples of learning activities for each unit are provided in the following sections. Examples highlighted by a shaded box are explained in detail in accompanying boxes. The examples that make use of information and communications technology are identified by this icon .

## Unit 1: The big ideas of chemistry

### AREA OF STUDY 1: The Periodic Table

#### Outcome 1

Explain how evidence is used to develop or refine chemical ideas and knowledge.

#### Examples of learning activities

conduct an introductory experiment to demonstrate the variety of ways elements and compounds can react; write precise observations using appropriate chemical vocabulary

discuss the advantage of devising a framework for the classification of chemical knowledge



carry out a group data sorting exercise; analyse the given physical and chemical properties of a number of elements and sort them into groups on the basis of similar properties

compare the groupings obtained in the data sorting exercise with Mendeleev's Periodic Table

discuss the work of Dalton and explain how evidence from accurately known atomic weights was used by Mendeleev to develop his Periodic Table

illustrate Dalton's theory that atoms are rearranged in chemical reactions by carrying out a series of experiments whereby a sample of copper is reacted to form a series of compounds and then reprecipitated as copper

prepare a short summary showing how the experimental evidence obtained by Thomson, Rutherford, Moseley and Chadwick was used to progressively modify and refine a model of the atom



research and report on the evidence provided by the work of another individual who has made a contribution to the development of the Periodic Table or atomic theory

perform calculations of relative atomic masses from abundances and relative isotopic masses

interpret mass spectra to determine relative atomic masses



conduct a web search to identify various forms of the current Periodic Table

conduct experiments demonstrating trends within the Periodic Table



based on data about the physical and chemical properties of a number of elements, and their position in the Periodic Table, in groups or individually predict the properties of other elements; compare predictions with actual properties

perform flame tests on selected metals



view emission spectra of various elements

interpret a series of ionisation energies as evidence for electron shells and subshells

conduct an experiment to distinguish between the reactivity of different metals, e.g. reaction with water, steam and dilute acid

perform simple displacement reactions to deduce an activity series of metals

draw a concept map of atomic theory using key terms

discuss the limitations of the current model of the atom

weigh out molar quantities of various metals

present a 'visualisation' of the mole to the class, e.g. a mole of grains of sand (dots on a page, dollars, heartbeats, etc) would look like



solve quantitative exercises involving the mole and Avogadro's constant

### Detailed example

#### DATA ANALYSIS TASK: GROUPING ELEMENTS ACCORDING TO PROPERTIES

##### Aims:

1. To introduce students to safe working habits in the laboratory.
2. To encourage careful observations and the use of precise chemical language.
3. To demonstrate the need and value of grouping elements according to properties to provide a framework for the study of Chemistry (teachers can use this exercise to introduce the concept of risk analysis including the identification of hazards associated with the use of chemicals and procedures used for minimising these risks).

##### Part A

##### Practical exercise

- a. Students examine a range of elements and their compounds and record their observations.

Examples: Na Ca Mg Al graphite Fe Zn Cu S and a range of ionic compounds.

Analysis of results: Students are asked to:

- group the elements on the basis of their properties and the chemical formulas of their compounds
- comment on the basis of the grouping chosen
- suggest why a framework for ordering chemical knowledge is useful.

##### Part B

##### Data sorting exercise

Students are provided with small cards, or a spreadsheet, with data on the properties of at least 30 elements. Data would include melting and boiling temperature, electrical conductivity, density, relative atomic weight, name and formula of common compounds.

Students place the elements in groups according to their properties and in order of increasing relative atomic weights. Within each group, they try to find trends or gradations in properties.

The groupings chosen, and the reasoning behind the choice of grouping, is compared between different members of the class.

##### Part C

##### Comparison with Mendeleev's Periodic Table

Students compare their groupings with those of Mendeleev and reflect on the similarities and differences between the two by considering the following questions:

- a. What difficulties did they encounter in devising their groups?
- b. What other information might have been useful?
- c. Why were there gaps in Mendeleev's table?
- d. How was Mendeleev's table useful as a predictive tool?

## AREA OF STUDY 2: Materials

**Outcome 2**

Use models of structure and bonding to explain the properties and applications of materials.

**Examples of learning activities**

investigate experimentally the conductivity (as a solid, melt and solution if soluble), hardness and ease of melting of a range of materials including examples from metallic, ionic and covalent substances



analyse results of investigation of materials in a spreadsheet to group materials according to properties



construct a model of a metallic lattice or view a computer simulation of a metallic lattice

discuss the properties of metals in terms of the simple metallic bonding model

grow and examine crystals of metals

investigate the effect of heat on metals



construct a model of part of an ionic lattice or view a computer simulation of an ionic lattice

discuss the properties of ionic compounds in terms of the ionic bonding model

examine the migration of coloured ions by simple electrophoresis

relate an element's position in the Periodic Table to its electrovalency

draw electron transfer diagrams for the formation of ionic compounds

write formulas of ionic compounds

determine experimentally the empirical formula of a compound such as magnesium oxide



view a computer simulation of the formation of a covalent bond

make a model of a diamond and graphite lattice, a 'bucky ball' and a nanotube and relate structure to properties and uses

draw Lewis structures for simple covalent molecular compounds that obey the octet rule

build models for simple covalent molecular compounds and sketch them to indicate their three-dimensional shape



view computer-generated models of covalent molecular compounds

predict shapes of simple covalent molecules that obey the octet rule

analyse boiling point data of a number of covalent molecular compounds; interpret and justify these in terms of intermolecular forces

construct concept maps to illustrate the links between the main ideas of metallic, ionic and covalent bonding and the properties of materials

using secondary sources, discuss some of the limitations of the models used to describe bonding

construct models of and provide systematic names for alkanes and alkenes to  $C_6$

construct models of and provide systematic names for structural isomers of butane



graph the boiling points of alkanes and explain these in terms of intermolecular bonding

compare the difference in reactivity of an alkane and an alkene towards bromine water in the dark and in the light

write equations for simple addition reactions of alkenes

model addition polymerisation by constructing polythene from monomer units of ethene

examine the properties and uses of a range of polymers formed by addition polymerisation of ethene and its derivatives

classify polymers as thermoplastic, thermosetting or elastomers on the basis of their properties and degree of cross linking



conduct a web search and write a report or prepare a web page on the development, properties and uses of a customised polymer such as dendrimers for use in medicine or intelligent polymers used in textiles

identify the limitations of the bonding model including the concept of 'incomplete' bonds at surfaces

model the relative scale of nanoparticles, e.g. in comparison to a mammalian cell

discuss the significance of size and surface area in the application of nanoparticles



investigate and report on one aspect of the uses of nanomolecules or an application of nanotechnology, e.g. in the manufacture of sunscreens

**Detailed example****PRESENTATION REPORT ON USES OF NANOTECHNOLOGY IN NEW MATERIALS****Nanoparticles**

Teachers provide students with recent articles about nanotechnology. These can often be found in the business and/or science section of newspapers, in science magazines or on the Internet (see Suitable Resources, p.64).

**Aim:** To develop an appreciation of the dimensions of nanoparticles and the applications of nanotechnology.

**Method**

1 nanometer (nm) is  $10^{-9}$ m. Such small sizes are very difficult to imagine. In this exercise, in order to visualise these small numbers, you will use one centimetre to represent one nanometer. Using this scale you will mark the length of various objects and so gain understanding of relative sizes.

Collect a roll of paper streamer. At the beginning of the streamer, mark a dot to represent the starting point. Along the streamer, each nm is to be represented by a distance of 1 centimetre.

Mark a spot 1cm from the starting point and label it '1nm'.

The list below shows the diameters of a number of objects. Scale each of them up by the factor of  $10^6$  and place a labelled spot on your streamer to represent that dimension.

**Mammalian cell**

- mitochondrion                      0.001 mm
- DNA                                       $2 \times 10^{-6}$  mm
- haemoglobin protein               $6 \times 10^{-6}$  mm

Bacillus Coli bacterium               $10^{-3}$  mm

Yellow fever virus                       $2 \times 10^{-5}$  mm

Calcium atom                               $4 \times 10^{-7}$  mm

Water molecule                           $2 \times 10^{-7}$  mm

**Questions**

1. a. Nanoparticles have dimensions between 1 and 100nm. Shade the region of your streamer to represent the range of nanoparticles. Which of the objects listed in the table would be of nanoparticles dimensions?
- b. A fine human hair has a diameter of one hundredth of a millimetre. If you were to mark the relative thickness of that hair on your streamer, how long would the streamer have to be?
- c. A human red blood cell has a diameter in the range of  $10^{-5}$ m. How does the size of a red blood cell compare with that of nanoparticles? Where would such a cell be placed on your streamer scale?
2. Explain why the surface interactions in nanoparticles are more significant than those in larger ones.
3. Suggest why nanoparticles, as opposed to larger ones, might be efficient as catalysts.
4. List some ways in which the behaviour of particles changes as their sizes fall below a certain level.
5. Research one of the following applications of nanotechnology. Present your findings in a written, oral or multimedia format.
  - a. Carbon nanotubes
  - b. Nanoparticles in sunscreens
  - c. Nanoparticles in textile fibres
  - d. Nanoparticles in electronics
  - e. Nanoparticles in medicine

## Unit 2: Environmental chemistry

### AREA OF STUDY 1: Water

#### Outcome 1

Write balanced equations and apply these to qualitative and quantitative investigations of reactions involving acids and bases, the formation of precipitates and gases, and oxidants and reductants.

#### Examples of learning activities

investigate some of the properties of water, e.g. specific heat capacity of water and density of water and ice

construct molecular models of the water molecule and a section of ice lattice

determine qualitatively the solubility of a variety of solid, liquid and gaseous solutes in water

draw a concept map summarising the different ways solutes dissolve in water

write equations for substances dissolving in water

test electrical conductivity of solutions and use structure and bonding



use a spreadsheet to plot a solubility curve derived from experimental data

calculate solution concentration in a range of units, e.g. mol/L, g/L and for solubility curves g/100 g solvent

perform dilution activities and calculate concentrations at each stage of dilution

use solubility data to purify a compound by recrystallisation

use solubility rules to predict the outcomes of precipitation reactions and experimentally test the predictions

write 'full' and ionic equations for precipitation reaction

investigate common reactions involving acids and bases and write balanced equations

identify acids, bases and ampholytes in a given equation according to the Bronsted-Lowry definition

relate the strength and concentration of acids and bases to the safety procedures for their use

differentiate between concentrated and strong acid



perform experiments to differentiate between strong and weak acids on the basis of conductivity, pH and rate of reaction with magnesium

formulate and write balanced chemical equations to demonstrate hydrolysis of acids and bases


explain the logarithmic nature of the pH scale



measure the pH of a range of acids and bases using a pH meter and data logger

investigate the pH of a variety of everyday solutions, e.g. drain cleaner (sodium hydroxide), cloudy ammonia, baking soda, battery acid (sulfuric acid), concrete cleaner (hydrochloric acid), vinegar, soft drinks, dishwashing powder (sodium carbonate)

perform dilutions of acids and bases and calculate their concentration and pH at each stage of dilution


 carry out an experiment to demonstrate that a tenfold dilution of an acid or base results in a pH change of one unit


investigate indicator colour at different pHs

solve simple stoichiometric problems including mass/mass, mass/volume, volume/volume and volume/concentration data

carry out simple gravimetric and volumetric experiments

solve quantitative exercises involving pH, concentration and dilutions

 use a pH meter and data logger to track changes in pH when a strong base is added to a strong acid

 use interactive software to investigate the titration curves of the reaction of strong/weak acids with strong/weak bases


carry out simple redox reactions, e.g. combustion of magnesium, metal displacement reactions, corrosion of iron

explain redox reactions in terms of electron transfer

demonstrate electron transfer using a galvanic cell

complete exercises describing simple oxidation and reduction in terms of half equations


use half equations to write fully balanced redox equations

 identify corrosion as a redox process and research and discuss the cost of corrosion to society

investigate first-hand sacrificial protection from corrosion


identify the likely solutes found in our waterways and the impact of human activity on their concentration

determine dissolved oxygen content of creek water

 review articles on environmental issues associated with water's solvent properties

use a probe to measure gas solubility at different temperatures and relate results to possible outcomes of global warming

 investigate the purification of domestic water supplies

 design a poster or web page illustrating desalination techniques for domestic, industrial and agricultural purposes in the context of clean water as a scarce resource

 use the web to identify the principles of green chemistry

select one of the principles of green chemistry and report on ways in which this principle is supported in industry

compare and evaluate a set of experimental procedures using the principles of green chemistry

use a jigsaw group exercise to investigate aspects of the nature of super critical (sc) CO<sub>2</sub> and its applications

brainstorm types of chemicals used to protect crops, e.g. insecticides, fungicides, herbicides

identify natural insecticides, e.g. pyrethroids; compare toxicity, LD50, of natural and synthetic insecticides



carry out a literature search on the use and environmental impact of DDT; investigate integrated pest management strategies in, for example, the cotton industry

### Detailed example

#### PRESENTATION REPORT ON GREEN CHEMISTRY

##### Super critical carbon dioxide: a group investigation

Super critical carbon dioxide has replaced conventional solvents in a number of industrial applications.

In your group you will investigate the nature and industrial applications of super critical carbon dioxide. Through your investigations you will become an expert on one aspect of super critical carbon dioxide. You will share your understandings with the other members of your group.

Your group will give an illustrated presentation about super critical carbon dioxide to the rest of the class and prepare notes and questions for use by other members of the class (when checked by your teacher).

Briefs for the experts:

**Expert 1.** You will investigate the nature of super critical carbon dioxide. You will use a phase diagram to illustrate, at a molecular level, the different phases of carbon dioxide and the transition between these phases. You will need to develop an understanding of how super critical carbon dioxide differs from the other phases of carbon dioxide.

**Experts 2, 3 & 4.** You will each research one industrial application of super critical carbon dioxide. You

will identify the solvent replaced by super critical carbon dioxide and explain the benefits of using super critical carbon dioxide. You will also identify the major stages of the process, and describe the uses of the products made by the process you have selected.

Some processes using super critical carbon dioxide you might investigate include:

- Decaffeination of coffee beans
- Extraction of flavours, from hops, for use in the brewing industry
- Use in the synthesis of polymers and pharmaceuticals
- Use in yarn sizing
- Use in cleaning and degreasing.

This example could be adapted to suit the following topics:

- Effect of human activities on the atmosphere.
- Maintenance of water quality.
- Salination of the water supply (and desalination technologies).
- Crop protection using environmentally sound solutions.

**AREA OF STUDY 2: The atmosphere****Outcome 2**

Explain how chemical reactions and processes occurring in the atmosphere help to sustain life on earth.

**Examples of learning activities**

brainstorm how the atmosphere is essential in maintaining life and how human activities impact on the composition of the atmosphere


demonstrate the formation of an acidic solution when the product of combustion of sulfur is added to water


investigate the effect of  $\text{SO}_2$  on seedlings


describe the formation and depletion of ozone by natural processes

list the pollutants and their sources that lead to the lowering of the ozone concentration in the upper atmosphere, and the formation of secondary pollutants in photochemical smog

discuss the environmental effects of ozone depletion and photochemical smog


 conduct web search on methods of reducing ozone depletion or the greenhouse effect or photochemical smog or acid rain

 participate in an ozone monitoring network

 produce a multimedia presentation explaining the importance of the carbon or nitrogen cycle to life on earth

prepare and test the properties of oxygen or carbon dioxide

demonstrate properties of dry ice (or liquid nitrogen)

 collect and evaluate the chemistry in media articles relating to the greenhouse effect

investigate properties of gases and explain in terms of kinetic molecular theory

discuss limitations of kinetic molecular theory

 perform experiments demonstrating Boyle's and Charles' laws; use a spreadsheet to record and graph results

perform calculations using Boyle's and Charles' laws and Avogadro's constant and the general (and ideal) gas equations

perform a first-hand investigation to determine the value of the molar volume of hydrogen gas at SLC and STP

perform calculations involving partial pressures

carry out simple stoichiometric exercises involving the mass and volume of gases

**Detailed example****SUMMARY REPORT: AN INVESTIGATION OF CARBON DIOXIDE**

The following is an example of a series of experiments that could be used as a basis for a summary report, including annotations, of three practical activities. Experimental details have not been included as they are readily available in various resource books.

**Practical Activity 1:** Formation of carbon dioxide

Aim: To prepare carbon dioxide through a range of chemical reactions.

Method: Reactions to investigate could include:

- Standard laboratory preparation using marble chips and acid in a Kipps apparatus.
- Acid on a hydrogen carbonate.
- Heating carbonates and hydrogen carbonates.
- Biological formation by fermentation.
- Biological formation in respiration.
- Burning coal.
- Combustion of a hydrocarbon (e.g. natural gas or a candle).

Equations are written and identified as acid/base, redox or other.

**Practical Activity 2:** Properties and uses of carbon dioxide

Aim:

- To determine the molar mass of carbon dioxide.
- To observe some of the other properties of carbon dioxide.

Method:

- Perform a quantitative experiment to determine the molar mass of carbon dioxide. Hence calculate the density of carbon dioxide and compare to that of air at the same temperature.

- Other properties to investigate qualitatively could include:

- density
- acidic properties – pH of aqueous solution, reaction with hydroxides (limewater test)
- fire extinguishing properties
- reaction with magnesium.

**Practical Activity 3:** Solubility of carbon dioxide at various temperatures

Students measure the amount of carbon dioxide released as the temperature of the contents of soda water is increased. The class discusses suitable experimental designs and selects two. Results for each are compared and the experimental designs rated for accuracy and reliability.

Students completing the summary report including annotations could include the types of reactions that involve carbon dioxide, the relationship between formation, properties and uses. The reactions that are leading to increased release of carbon dioxide into the atmosphere can be identified and related to the carbon cycle in nature and the enhanced greenhouse effect. The significance of the solubility characteristics of carbon dioxide can be related to the effect of increased global temperatures on the carbon dioxide 'sinks' in the oceans. The importance of reliable and accurate empirical evidence in explaining and/or supporting theories or influencing opinions (public, governments, scientific community) could be discussed.

Footnote: This activity could be suitable as an extended experimental investigation where students design experiments in which they could measure either the amount of carbon dioxide that remains dissolved (e.g. using pH measurement) or how much gas is released as the temperature changes. A can of soda water could be used as a source of dissolved carbon dioxide. Students could then investigate other properties and reactions of carbon dioxide.

## Unit 3: Chemical pathways

### AREA OF STUDY 1: Chemical analysis

#### Outcome 1

Evaluate the suitability of techniques and instruments used in chemical analyses.

#### Examples of learning activities

discuss the role of chemical analysis in determining the quality of consumer goods

discuss the relationship between the properties of the chemical under investigation and techniques of analysis

review stoichiometry including balancing equations

practice use of volumetric equipment and discuss their accuracy

discuss equivalence and end point of a reaction; limitations of volumetric analysis

investigate pH at which indicators change colour; discuss criteria for selection of an indicator for a particular reaction

prepare a standard solution and use this to find the concentration of an acid or base

discuss criteria for selection of primary standards

carry out volumetric analysis of acid/base content of consumer products, e.g. acid content of vinegar or white wine or orange juice, mass HCl in concrete cleaner, carbon dioxide content of fizzy drinks, carbonate content of health salts, mass of ammonia in household cleaner

solve quantitative exercises involving acid base reactions; use volume, concentration and mass of reactants



use a computer simulation to track pH changes in the course of a titration

discuss the concept of oxidation numbers; write half equations, and full equations, for more complex redox reactions restricted to acid conditions only

solve quantitative exercise involving redox reactions

carry out volumetric analysis involving redox reactions, e.g. standardisation of potassium permanganate, and use this to determine the concentration of a hydrogen peroxide solution or to determine percentage of iron in steel wool

solve quantitative exercise involving back titrations

conduct a back titration, e.g. nitrogen content of fertiliser

discuss principles and application of gravimetric analysis

conduct a gravimetric analysis such as the determination of the salt content of saline water, sulfate content of fertiliser

solve quantitative exercise involving gravimetric analysis

complete exercises requiring the calculation of a combination of an amount of solids, liquids and gases, solution concentration or volume and the volume, temperature and pressure of gases



research and discuss general principles and applications of chromatography

experimentally investigate a range of simple chromatographic techniques, e.g. paper, thin layer, column, calculation of  $R_f$  values

use chromatogram and table of  $R_f$  values to identify component in a mixture

discuss advanced chromatographic techniques, e.g. TLC, HPLC and GC

undertake quantitative and qualitative exercises involving interpretation of chromatograms



research and discuss principles and application of UV/visible spectroscopy

perform flame tests to identify unknown metal cations

identify metal by comparison of its spectrum with that of known metals

discuss the principles of colorimetry, and the relationship between concentration and absorption

use second-hand colorimetry data to construct a calibration curve and determine the concentration of an ingredient in a consumer product, concentration of phosphate ions in laundry products

perform a colorimetric analysis such as the phosphate content of washing powders



research and discuss principles and applications of atomic absorption spectroscopy

use second-hand atomic absorption spectroscopy data to determine, for example, the iron content in waste water storage ponds



research the principles of mass spectroscopy and interpretation of mass spectrographs of atoms and molecules

discuss principles and application of infrared spectroscopy, and interpretation of simple IR spectrographs

discuss principles and application of NMR and interpret some simple NMR spectrographs in determining the composition and structure of an unknown compound

use data from a number of analytical techniques to determine the identity of a compound

construct a summary table of various volumetric, chromatographic and spectroscopic techniques (include the property at the atomic or molecular level of the substance under investigation on which the technique is based, and examples of uses)

complete exercises involving the identification of an appropriate analytic technique for a specified purpose



research and prepare a report on the use of the synchrotron as an analytical instrument

Note: students are required to know the general principles of the instrumentation used in various chromatographic and spectroscopic techniques; they are not expected to recall specific technical detail.

**Detailed example 1****DATA ANALYSIS TASK: INTERPRETATION OF DATA**

A chemical company regularly monitors the level of iron(II) ions discharged into waste water storage ponds.

The colourless  $\text{Fe}^{2+}$  ion are converted to an orange coloured complex, iron(II) phenanthroline ( $\text{Fe}(\text{phen})_3^{2+}$ ). The absorbance of this coloured complex is measured in a colorimeter and the absorbance of a number of solutions of a known concentration of iron(II) phenanthroline are plotted on a calibration graph. The absorbance of the  $\text{Fe}(\text{phen})_3^{2+}$  in the water sample is used to read off the concentration of  $\text{Fe}^{2+}$  from the calibration graph.

The results of one such analysis are indicated below.

Concentration of $\text{Fe}^{2+}$ (ppm)	Absorbance
1 ppm	0.184
2 ppm	0.358
3 ppm	0.540
4 ppm	0.735
5 ppm	0.896
Sample	0.452

1. Plot the absorbance data for the five standard solutions against concentration. Are the plots in a straight line? Would a straight line be expected?
2. Draw a line of best fit. How is a line of best fit determined?
3. Use the line of best fit to determine the concentration of  $\text{Fe}^{2+}$  in the factory's waste water.
4. Enter the absorbance data for the five standard solutions onto a spreadsheet.
5. Use the spreadsheet chart function to graphically represent the data.
6. Now use the spreadsheet's linear regression function to display the equation for the line of best fit.
7. Use this equation to calculate the concentration of  $\text{Fe}^{2+}$  in the waste water.
8. Compare your answer with that obtained in question 3.

**Detailed example 2****DATA ANALYSIS TASK: USING ANALYTICAL TECHNIQUES TO DETERMINE COMPOSITION AND STRUCTURE**

Chemical analysis of combustion products indicated the percentage of carbon hydrogen and oxygen in an unknown compound. This data enabled the empirical formula to be identified as  $C_3H_6O_2$ .

The mass spectrum of the unknown compound indicated that the molecular ion had a relative molecular mass of 74.

Using this and the empirical formula determined the molecular formula to be  $C_3H_6O_2$ .

There are three structural isomers corresponding to this molecular formula:

1.  $CH_3CH_2COOH$  propanoic acid or
2.  $CH_3COOCH_3$  methyl ethanoate or
3.  $HCOOCH_2CH_3$  ethyl methanoate.

Using data tables, the position of the absorption peaks in the infrared spectrum can be used to identify presence of:

- 2980  $cm^{-1}$  C-H bonds  
1725  $cm^{-1}$  C=O bonds  
1200  $cm^{-1}$  C-O bonds.

The low resolution NMR spectrum indicates that the hydrogens exist in three different chemical environments.

The integration trace indicated the ratio of hydrogen atom in these environments as 3:2:1.

The high resolution NMR spectrum provides a measure of the chemical shift. Reference to chemical shift data tables indicates the presence of:

- 1.3 R-  $CH_3$  group  
4.2 R- $COOCH_2$  - R, group  
8.1 H- $COO$ -R group.

The splitting patterns are used to identify the number of adjacent hydrogen atoms

- 1.3 triplet: two adjacent hydrogen atoms :  $CH_2$  next to  $CH_3$  i.e. -  $COOCH_2$  -  $CH_3$   
4.2 quartet: three adjacent hydrogen atoms  $CH_3$  next to  $CH_2$  i.e. -  $COOCH_2$  -  $CH_3$   
8.1 single: zero adjacent hydrogen atoms H- $COO$  i.e.  $HCOOCH_2CH_3$

This data is consistent with the structure 3.

Note. Spectra can be found in many textbooks and websites (see Suitable Resources, p.64).

**AREA OF STUDY 2: Organic chemical pathways****Outcome 2**

Identify and explain the role of functional groups in organic reactions and construct reaction pathways using organic molecules.

**Examples of learning activities**

investigate the principles of fractional distillation of crude oil and the composition and uses of the different fractions



construct models (or examine computer models) and provide systematic names for alkanes, alkenes, amine, chloroalkanes, alkanols, alkanolic acids (carboxylic acids) to  $C_{10}$  (molecules should be restricted to no more than 1 functional group; structural isomers should be investigated; geometric and optical isomers are NOT required)

prepare a summary sheet or flow chart outlining the rules for naming organic compounds

investigate the chemical reactions of alkanes, alkenes, amines, chloroalkanes, alkanols and carboxylic acids

prepare some esters

construct a flow chart to show the production of esters from alkenes

discuss the formation of condensation polymers

identify the ester link in a polyester and the amide link in a polyamide

observe the formation of a condensation polymer such as Nylon

identify the repeating unit of a polymer given the structural formula of a section of a chain

identify the functional groups present in monosaccharides and write equations to show how monosaccharides condense to form disaccharides and polysaccharides

identify the functional groups present in glycerol and fatty acids and write equations to show how these molecules condense to form fats

identify the functional groups present in 2-amino acids, and write equations to show how 2-amino acids condense to form polypeptides and proteins



use molecular model kits, computer simulations or other multimedia resources to describe the composition and generalised structure of proteins

use a paper streamer to model the primary, secondary, tertiary and quaternary structure of proteins

identify the type of bonding involved in maintaining the primary, secondary and tertiary structure of proteins

model the 'lock and key' mechanism of enzyme action and discuss its significance in the functioning of enzymes in biochemical reactions

perform first-hand investigations to observe the effect of changes in pH and temperature on the reaction of a named enzyme; use the available evidence to relate this to possible changes in the primary, secondary and/or tertiary structure of the enzyme involved

identify cellulose as an example of a condensation polymer found as a major component of biomass and discuss its potential as a fuel

write an equation for the fermentation of glucose

process information from secondary sources to summarise the processes involved in the industrial production of ethanol from sugar cane

plan and perform an experiment to demonstrate the fermentation of glucose under different temperature conditions, monitoring reaction progress by mass changes



collect information about the production, use and environmental impact of other biofuels

model the structure of DNA in terms of pentose sugar, phosphate and nitrogen base repeating units

identify the sites of hydrogen bonding between complementary bases of the two strands of DNA given their structural formulas



examine a computer simulation of the three-dimensional structure of DNA

discuss the importance of accuracy in forensic chemistry

discuss the application of DNA analysis in forensic chemistry and the ethics of maintenance of data banks of DNA

relate the sequence of base pairs in DNA to the formation of proteins

discuss how identification of proteins present in an individual can be used to identify and potentially treat disease

prepare and analyse a sample of aspirin

compare the structure and functional groups present in a series of similar medicines

Note: it is not intended that students recall the structure of individual biomolecules; the focus should be on the functional groups within the biomolecule and the way smaller molecules condense and polymerise to form larger ones; similarly, given a large biomolecule, students should be able to deduce the product of its hydrolysis.

**Detailed example****EXTENDED EXPERIMENTAL INVESTIGATION****Study of aspirin**

This detailed example is based on a series of worksheets devised by the Royal Chemical Society. Experimental detail (including safety), teacher notes and sample questions are accessible on [www.chemistry-react.org/go/Tutorial/Tutorial\\_21681.html](http://www.chemistry-react.org/go/Tutorial/Tutorial_21681.html)

Information regarding the production of aspirin can also be found in most chemistry laboratory manuals.

**Part A**

Prepare a short presentation about aspirin. Include the conditions that aspirin helps to relieve or cure, the side effects of aspirin, and the alternative treatments for people who are affected by aspirin. Describe the chemistry involved in developing the medicine in a usable form.

**Part B**

Prepare a sample of aspirin and purify it by recrystallisation.

Calculate percentage yield.

**Part C**

Test for purity using

- $\text{FeCl}_3$
- a melting point determination.

**Part D**

Investigate aspirin using thin layer chromatography.

**Part E**

Test the solubility of aspirin and relate this to its role as a medicine.

**Part F**

Construct a labelled Reaction Pathway for the production of aspirin, clearly showing relevant functional groups.

## Unit 4: Chemistry at work

### AREA OF STUDY 1: Industrial chemistry

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#### Outcome 1

Analyse the factors that determine the optimum conditions used in the industrial production of the selected chemical.

#### Examples of learning activities

observe fast and slow chemical reactions

identify everyday situations where fast and slow reactions are desirable

revise kinetic molecular theory

discuss the idea that chemical reactions involve the breaking and making of bonds



develop a PowerPoint animation to illustrate the collision theory of reactions

illustrate the concept of activation energy using energy profile diagrams for endothermic and exothermic reactions

use data to measure the variation of the rate of a reaction with time

demonstrate that the rate of reaction depends on frequency of collisions using reaction between lead nitrate and potassium iodide in the solid and aqueous states

design an experiment to investigate the effect of particle size on the rate of reaction



conduct a laboratory investigation of the effect of concentration on the rate of reaction

use data to explain the impact of pressure on the rate of a gaseous reaction



carry out a laboratory investigation on the effect of temperature on the rate of reaction; explain observations in terms of the distribution of kinetic energies at different temperatures

demonstrate use of a catalyst to increase the rate of reaction

investigate the mechanism of catalysts



conduct a web search on the use of industrial catalysts

conduct a laboratory investigation of the reversible nature of reactions

interpret evidence for the dynamic nature of equilibrium



use a spreadsheet to manipulate data to illustrate the constancy of  $K_{eq}$  at constant temperature

perform calculations based on the equilibrium law, concentrations and  $K_{eq}$

discuss evidence for ionisation of water

discuss the definition and application of  $K_w$

perform calculations to determine the concentration of  $H_3O^+$  and  $OH^-$  ions in acidic and alkaline solutions

perform calculations to determine the pH of acidic and alkaline solutions including dilutions

design an experiment to investigate the pH at which various indicators change colours

experimentally determine  $K_a$  for ethanoic acid

perform calculations involving  $K_a$  for weak acids

investigate rate and equilibrium considerations and the use of catalysts

investigate the factors affecting the production of a chemical; present a report



brainstorm factors impacting on the manufacture of a selected chemical, e.g. ammonia

identify how the use of a selected chemical is related to its properties and structure; present a report on the selected chemical including production, wastes, and methods used to minimise the environmental impact



research the labelling of hazardous materials; identify safety procedures to be followed when handling specific chemicals

conduct a safety audit prior to any laboratory investigation



research and identify the safety and waste management practices common to the industrial production of chemicals

conduct a laboratory investigation of the effect of changing concentration on equilibrium position; demonstrate the effect of changing pressure and temperature on an equilibrium system

**Detailed example 1**

## REPORT ON CHEMISTRY AT WORK

**A. Factors affecting the industrial production of a particular chemical**

The industrial preparation of chemicals involves consideration of yield and rate. Often the optimum reaction conditions are a compromise to ensure a reasonable yield within an acceptable time.

The industrial preparation of methanol involves such considerations. The process involves three main stages:

- (i) Reaction of methane with steam to produce carbon monoxide and hydrogen.
  - (ii) Conversion of carbon monoxide and hydrogen to produce methanol.
  - (iii) Separation of the methanol from the reaction mixture.
1. Write equations for the reactions occurring in steps (i) and (ii).
  2. What separation techniques would be suitable for separating the methanol from the reaction mixture in the last stage?

The reaction in step (ii) between carbon monoxide and hydrogen is exothermic and is carried out at 250°C and 100atm. Pressure. About 10% of the reactants are converted to methanol.

3. Discuss how these reaction conditions affect the yield of methanol and the rate at which it is produced.
  4. How would the yield of methanol produced be affected if:
    - (i) The temperature is increased?
    - (ii) The pressure is increased?
1. What design features should be included in the plant to ensure that a greater proportion of the reactants are converted to methanol?
  2. Draw a sketch or flow chart showing the sequence of stages involved in the industrial preparation of methanol. Include any ideas for recycling unused reactants and the heat produced by the reaction.
  3. Use the web to investigate the industrial uses of methanol, and associated safety and waste management.

**OR**

**Detailed example 2**

## RESPONSE TO STIMULUS MATERIAL RELATED TO CHEMISTRY AT WORK

**B. Which raw material is more efficient?**

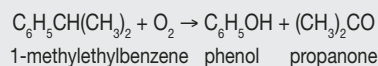
One of the factors that needs to be taken into account when designing a chemical plant, is the cost of raw materials and the chemical's selling price. A variety of suitable raw materials may be available.

Phenol,  $\text{C}_6\text{H}_5\text{OH}$ , is an important industrial chemical. Large amounts are produced mostly as an intermediate in the production of other chemicals used in manufacture of resins for the plywood, construction, automotive, and appliance industries. It is also used in the manufacture of nylon and epoxy resins. Phenol is used as a disinfectant, and in ear and nose drops, throat lozenges, and mouthwashes and in the manufacture of pharmaceuticals. It is also used in the manufacture of dyes, fertilisers, explosives, paints and paint removers, and textiles and coke.

It can be prepared from a number of raw materials including benzene,  $\text{C}_6\text{H}_6$ , methyl benzene  $\text{C}_6\text{H}_5\text{CH}_3$  and 1-methylethylbenzene  $\text{C}_6\text{H}_5\text{CH}(\text{CH}_3)_2$

1. Calculate the mass of reactant needed to produce 1 tonne of phenol from each of these raw materials. Assume that there is 100% conversion of the raw material to phenol.

2. Which raw material would be the most economical if the cost per tonne was the same for each.
3. In reality a 100% conversion is not always possible. What other factors must be taken into account when selecting the best raw material for the manufacture of phenol?
4. Some reactions produce by-products which can also be sold. For example, the process using 1-methylethylbenzene also produces propanone,  $(\text{CH}_3)_2\text{CO}$ , as a useful by-product which can be sold. The common name for propanone is acetone.



- (i) What mass of propanone is produced for every tonne of phenol?
- (ii) Use the web to find out about the uses of propanone.

Would this method of phenol production be economical if there was no market for propanone?

**OR**

**Detailed example 3**

## A SUMMARY REPORT (INCLUDING ANNOTATIONS)

**C. Practical investigation of factors that effect equilibrium systems**

Students complete a set of practical activities that investigate the effect of factors such as temperature, concentration and pressure on equilibrium systems.

Students record and annotate their observations. They design and complete a table that summarises how particular changes affect equilibrium. Students then show how the relevant factors are addressed in the selected chemical.

## AREA OF STUDY 2: Supplying and using energy

**Outcome 2**

Analyse chemical and energy transformations occurring in chemical reactions.

**Examples of learning activities**

use the web and other sources to investigate the use, sustainability and environmental impact of an alternative energy source and present a report; possible energy sources are brown coal, natural gas, nuclear fission and biochemical

define exothermic and endothermic, and identify useful endothermic and exothermic reactions

interpret enthalpy diagrams

relate chemical energy to interactions between subatomic particles and energy levels within atoms and molecules; relate heats of reaction to bond energy

conduct an experiment investigating the relationship between the amount of a substance and the heat released

perform calculations using thermochemical equations

discuss the relationship between energy and temperature change



calibrate a calorimeter and use a data logger to determine the enthalpy for a chemical reaction, e.g. hydrochloric acid and sodium hydroxide or heat of hydration of copper(II) sulfate

complete numerical exercises involving calibration and the determination of heats of reaction

compare heats of combustion of various fuels

complete exercises involving the manipulation of heats of reaction

review oxidation and reduction, oxidation number and writing half and full equations



conduct experiments to determine the relative ease of oxidation of metals

predict the product of chemical reactions using the electrochemical series; experimentally test these predictions and write half and full equations for these reactions

identify the limitations of the use of the electrochemical series

construct simple galvanic cells and explain in general principles their operation in terms of reactions occurring at the electrodes and the movement of electrons and ions (the focus is on the application of general principles rather than details for specific cells)

investigate and prepare a report on the operation of a specific cell such as a dry cell or alkaline cell



research and investigate the general principles behind the operation of rechargeable cells, e.g. car battery, NiCAD and lithium cell



design a poster showing the operation of a fuel cell

analyse second-hand data on the use of hydrogen as a fuel



use the web to investigate developments and applications of fuel cell technology;  
compare the advantages and disadvantages of fuel cells with other energy sources

construct a simple electrolytic cell

identify the factors that determine the products of electrolysis

use electrochemical series to predict the outcome of competing electrode reactions

analyse data showing the relationship between amount of metal deposited in an electrolytic cell and charge flowing through the cell

use Faraday's laws in quantitative calculations



research and outline the advantages and disadvantages of the use of ethanol as an alternative car fuel, explain why it can be called a renewable resource and evaluate the success of current usage

### Detailed example

#### ANALYSIS OF SECOND-HAND DATA USING STRUCTURED QUESTIONS

##### The 'Hydrogen Economy'

During the 1970s the idea of a 'hydrogen economy', an energy system based on hydrogen rather than fossil fuels such as coal, natural gas and petroleum, was first discussed.

- Investigate the advantages and disadvantages of using hydrogen as an energy source.

Since the invention of the internal combustion engine a complex system has evolved that ensures the distribution of petrol to the customer. This involves the location of crude oil deposits, its extraction and transport to refineries, the separation of petrol from crude oil, its safe storage and distribution to service stations.

- What are the possible sources of hydrogen for use as fuel? How could the hydrogen be extracted? How could it be stored and distributed to the customer?  
  
Hydrogen can be used as an energy source to power cars. In the hydrogen engine hydrogen can be burned to produce heat energy which powers a car in a similar way that the heat in a petrol engine is used to power a car. Cars can also be powered by electrical energy generated in hydrogen fuel cells.
- Write equations that describe the complete combustion of petrol (octane,  $C_8H_{18}$ ) and hydrogen.

- What is the environmental impact of the waste gases produced by these reactions?
- What mass of hydrogen needs to be burned to produce the same energy as the complete combustion of a tank of petrol?

Assume that:

petrol only contains octane,  $C_8H_{18}$ ;

one litre of octane weighs 0.7 kg;

the tank of a medium sized car has a capacity of 60 litres;

The standard heat of combustion of octane =  $-5500 \text{ kJmol}^{-1}$ ;

The standard heat of combustion of hydrogen =  $-286 \text{ kJmol}^{-1}$ .

William Grove demonstrated the principles of the hydrogen fuel cell in 1839. Fuel cells were used in the 1960s to provide electrical power in the Apollo space flights to the moon. Today major car manufacturers are developing cars powered by hydrogen fuel cells. In many cities around the world fuel cells are used to power buses and taxis.

- What is a fuel cell?
- Briefly outline the operation of a fuel cell.
- Outline the advantages and disadvantages of using fuel cells to power cars.

continued

**Detailed example (continued)**

9. Use a flow chart to outline the energy changes that occur in a car fuelled by petrol and in an electric car powered by a fuel cell.

Different types of fuel cells have been developed. They use different fuels and electrolytes and operate at different temperatures.

The Polymer Electrolyte Membrane (PEM) fuel cell is considered to be the most appropriate for use in cars. It is low maintenance and operates at low temperature but is affected by impurities in the fuel. Electricity is produced when hydrogen is oxidised at the anode and oxygen is reduced at the cathode.

10. Write half equations for these reactions and write an overall equation for the reactions occurring in the cell.

The fuel cell used in the Apollo space missions was an Alkaline Fuel Cell. This is a high performance fuel cell where hydrogen is oxidised to water in the presence of hydroxide ions and oxygen in the presence of water is reduced to hydroxide ions.

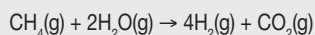
11. Write the equations occurring at the anode and cathode.

The Ceramic Fuel Cell was developed in Australia by the CSIRO. This fuel cell operates at a high temperature and generates electrical energy by using a variety of fuels such as methane or methanol.

12. Use the web to further investigate Ceramic Fuel Cells. What reactions occur at the anode and cathode? What are the advantages of this type of cell over other fuel cells? What are its applications?

More information about fuel cells can be found at <http://education.lanl.gov/resources/fuelcells/> and [www.fuelcells.org.au](http://www.fuelcells.org.au)

It is claimed that hydrogen engines and hydrogen fuel cells are more environmentally friendly than petrol driven cars. The manner in which hydrogen is produced needs to be taken into account when considering this statement. The most common industrial method of producing hydrogen is by reforming natural gas.



A by-product of this reaction is carbon dioxide, a greenhouse gas.

13. Describe some alternative ways of producing hydrogen that do not generate greenhouse gases as a waste product.

## SCHOOL-ASSESSED COURSEWORK

In Units 3 and 4 teachers must select appropriate tasks from the assessment table provided for each unit. Advice on the assessment tasks and performance descriptors to assist teachers in designing and marking assessment tasks will be published by the Victorian Curriculum and Assessment Authority in an assessment handbook. The following is an example of each assessment task from the Units 3 and 4 assessment tables. Teachers would construct an assessment program using a selection of the following tasks.

Outcomes	Marks allocated	Assessment tasks
<b>Unit 3</b> <b>Outcome 1</b> Evaluate the suitability of techniques and instruments used in chemical analyses.	50	An extended experimental investigation from either area of study. (Area of study 1) Analysis of fertilisers – $\text{NH}_4^+$ by back titration, $\text{SO}_4^{2-}$ by gravimetric, $\text{PO}_4^{3-}$ calorimetrically <b>OR</b> (Area of study 2) Aspirin 1. Preparation and purification of aspirin. 2. Determination of the amount of aspirin in an analgesic. 3. Thin layer chromatography of pain killers. <b>AND</b> A written report of one practical activity (from the area of study not used in the extended experimental investigation). (Area of study 1) Phosphate content of washing powders by colorimetric analysis. <b>OR</b> Preparation of standard permanganate solution and using it to analyse a peroxide solution. <b>OR</b> (Area of study 2) Investigation of the effect of temperature and pH on enzyme activity. <b>AND ONE OF</b>
<b>Outcome 2</b> Identify and explain the role of functional groups in organic reactions and construct reaction pathways using organic molecules.	25	

*continued*

*continued Unit 3*

25

A response to stimulus material in written, oral or visual format.

Use media article on drugs in sport to give a presentation on the variety of instruments used in modern-day chemical analysis.

**OR**

Ethical issues regarding DNA profiling.

Analysis of first and second-hand data using structured questions.

Use analytical techniques and spectroscopy data to identify an unknown compound.

**OR**

Identification of functional groups in medicines and drugs.

A report in written, oral, multimedia or visual format related to chemical pathways.

Prepare a report comparing the preparation of ibuprofen using green and brown chemical pathways.

**OR**

The role of proteins as markers for disease.

**Total marks for Unit 3****100**

Outcomes	Marks allocated	Assessment tasks
<b>Unit 4</b>		
<b>Outcome 1</b> Analyse the factors that determine the optimum conditions used in the industrial production of the selected chemical.	50	<p>A summary report including annotations of three practical activities drawn from either area of study. (Area of study 1)</p> <p>Investigating factors affecting rate of reaction.</p> <ol style="list-style-type: none"> <li>1. Effect of particle size on rate.</li> <li>2. Effect of concentration on rate.</li> <li>3. Effect of temperature on rate.</li> </ol> <p><b>AND</b></p>
<b>Outcome 2</b> Analyse chemical and energy transformations occurring in chemical reactions.	25	<p>A written report of one practical activity (from the area of study not used in the annotated portfolio). (Area of study 2)</p> <p>Calibration of a calorimeter</p> <p><b>OR</b></p> <p>Measuring heats of reaction</p> <p><b>OR</b></p> <p>Application of Faraday's laws</p> <p><b>OR</b></p> <p>Predict the products of electrolysis and test these predictions.</p> <p><b>AND ONE OF</b></p>
	25	<p>A response to stimulus material in written, oral or visual format.</p> <p>Use a newspaper article on ceramic fuel cells as part of a presentation on advantages and disadvantages of fuel cells compared with conventional energy sources.</p> <p>Analysis of first and second-hand data using structured questions.</p> <p>Analyse data comparing the amount of metal deposited in an electrolytic cell and charge flowing through the cell. Use the results of this analysis to develop a general statement linking the amount of metal deposited to the charge and the valency of the metal ion.</p> <p>A report in written, oral, multimedia or visual format related to chemistry at work.</p> <p>Design a web page linking sites providing information about safe use of chemicals in industrial and domestic situations.</p> <p><b>OR</b></p> <p>Develop a PowerPoint animation to illustrate application of Le Chatelier's Principle to an industrial process.</p>
<b>Total marks for Unit 4</b>	<b>100</b>	

## SUITABLE RESOURCES

Courses must be developed within the framework of the study design: the areas of study, outcome statements, and key knowledge and skills.

Some of the print resources listed in this section may be out of print. They have been included because they may still be available from libraries, bookshops and private collections.

At the time of publication the URLs (website addresses) cited were checked for accuracy and appropriateness of content. However, due to the transient nature of material placed on the web, their continuing accuracy cannot be verified. Teachers are strongly advised to prepare their own indexes of sites that are suitable and applicable to the courses they teach, and to check these addresses prior to allowing student access.

### BOOKS

Aylward, GH & Finlay, TJV 2002, *SI Chemical Data*, 5th edn, John Wiley & Sons, Australia.

Bradfield, R & Hogendoorn, B, *Sustainable Agriculture*, STAV.

Bucat, RP 1984, *Elements of Chemistry, Earth, Air, Fire and Water*, vols 1 & 2, Australian Academy of Science, Canberra, Australia.

Cann, MC & Connelly, ME 2000, *Real World Cases in Green Chemistry*, American Chemical Society, Washington DC.

Chemistry Education Association 1982, *Chemistry: Key to the Earth*, Melbourne University Press, Carlton.

Commons, C et al. 2002, *Chemistry two*, 3rd edn, Heinemann, Victoria.

Commons, C 2006 *Heinemann Chemistry Two*, Third Edition (student book), Heinemann, Victoria.

Commons & Hogendoorn 1995, *Demonstrations for Secondary School Chemistry*, 2nd edn, Heinemann/CEA, Victorian.

Derbogolian, M et al. 2000, *Chemical Connections 1*, 3rd edn, Jacaranda, Australia.

Derbogolian, M et al. 2006, *Study on Chemistry 1. VCE Chemistry Units 1 & 2 Chemical Connections*, Jacaranda Press, Australia.

Elvins, C et al. 2002, *Chemistry one*, 3rd edn, Heinemann, Victoria.

Hill, G & Holman, J 1995, *Chemistry in Context*, Nelson, Australia.

Hill, G & Holman, J 1995, *Chemistry in Context Laboratory Manual*, Nelson, Australia.

Hogendoorn et al., 2006 *Heinemann Chemistry Two* Fourth Edition (textbook and CD), Heinemann, Victoria.

Huddard, 2006, *Heinemann Chemistry One* (student book), Heinemann, Victoria.

Lukins, N et al. 2006, *Heinemann Chemistry One* Fourth Edition Pack, Heinemann, Victoria.

McTigue, PT 1982, *Chemistry: A Key to the Earth*, 2nd edn, Melbourne University Press, Australia.

Mulhall, D 2002, *Our Molecular Future*, Prometheus Books, New York.

Neuss, G 2001, *Chemistry for the IB Diploma*, Standards and higher level (IB Study Guide Series), Oxford University Press.

Ryan, M & Tinnesand, MJ 2002, *Introduction to Green Chemistry*, American Chemical Society, Washington DC.

Salters Advanced Chemistry 2000, *Chemical Ideas*, 2nd edn, Heinemann, UK.

Salters Advanced Chemistry 2000, *Chemical Storylines*, 2nd edn, Heinemann, UK.

Selinger, B 1997, *Chemistry in the Market Place*, 5th edn, Harcourt Brace Jovanich, Marrickville.

Sharwood, J et al. 2006, *Nelson Chemistry VCE Units 1 & 2*, 2nd edn (textbook, student CD-ROM, practical manual, teacher CD-ROM), Nelson, Melbourne.

Sharwood, J et al., *Nelson Chemistry VCE Units 3 & 4*, 2nd edn, textbook, (student CD-ROM, practical manual, teacher CD-ROM), Nelson, Melbourne. (To be published in 2007.)

Smith, A & Dwyer, C 1991, *Key Chemistry*, Melbourne University Press, Carlton.

Snape, D 1989, *Meet the First Thirty Elements*, STAV, Melbourne.

Spence, R, Bramley, L, Gemellaro, T, Wilson, D & Wiseman, S 2004, *Chemistry A Contextual Approach*, Heinemann Queensland Science Project, Victoria.

Stokes, R et al. 1999, *Chemical Connections 2*, 2nd edn, Jacaranda, Australia.

Stokes, R et al., 2006 *Study on Chemistry 2 VCE Chemistry Units 3 & 4*, Chemical Connections, (includes CD-ROM with full text PDF and interactive activities), Jacaranda Press, Australia.

Zumdahl S & Zumdahl S 2003, *Chemistry*, 6th edn, Houghton Mifflin, Boston and New York.

**JOURNALS AND PERIODICALS**

*Chem Matters*, American Chemical Society (available through RACI, PO Box 28, Kensington Park, SA 5068)

*CHEM 13 news*, Department of Chemistry, University of Waterloo, Waterloo, Ontario N2L 3G1 Canada  
[www.science.uwaterloo.ca/chem13news/](http://www.science.uwaterloo.ca/chem13news/)

*Choice Magazine*, Australia

*Cosmos Magazine*

*Double Helix Magazine* (CSIRO)

*Labtalk* (STAV)

*Nature*

*New Scientist*, UK

*Scientific American*

**WEBSITES****General**

[www.abc.net.au/science/news/stories](http://www.abc.net.au/science/news/stories)

<http://antoine.frostburg.edu/cgi-bin/senese/tutorials/isomer/index.cgi?n=3&list=400>  
(isomer construction)

<http://antoine.frostburg.edu/chem/senese/101/index.shtml>

[www.avogadro.co.uk/](http://www.avogadro.co.uk/)

[www.chem.leeds.ac.uk/delights/](http://www.chem.leeds.ac.uk/delights/)

[www.creative-chemistry.org.uk/index.htm](http://www.creative-chemistry.org.uk/index.htm)

[www.csiro.au/helix/sciencemail/index.html](http://www.csiro.au/helix/sciencemail/index.html)

<http://genchem.chem.wisc.edu/demonstrations/>

[www.greenhouse.gov.au/](http://www.greenhouse.gov.au/)

[www.iupac.org/publications/ci/index.html](http://www.iupac.org/publications/ci/index.html)

[www.jaonline.com.au](http://www.jaonline.com.au)

VCE Chemistry Teacher Support Kit, includes practical experiments, activities, assessment materials, MSDS sheets and advice for teachers. Student resource website: Study on Chemistry 1 & 2

<http://javalab.uoregon.edu/dcaley/elements/Elements.html>  
(absorption and emission spectra)

[www.minerals.org.au/education](http://www.minerals.org.au/education)

[www.privatehand.com/flash/elements.html](http://www.privatehand.com/flash/elements.html)

<http://profilesnih.gov/>

[www.science.org.au/nova/](http://www.science.org.au/nova/)

[http://velocity.ansto.gov.au/velocity/ans0008/email\\_online.asp](http://velocity.ansto.gov.au/velocity/ans0008/email_online.asp)

**Periodic Table**

[www.usetute.com.au/ptistor.html](http://www.usetute.com.au/ptistor.html)

[www.kids.net.au/encyclopedia-wiki/pe/Periodic\\_table](http://www.kids.net.au/encyclopedia-wiki/pe/Periodic_table)

[http://au.dir.yahoo.com/Science/Chemistry/Periodic\\_Table\\_of\\_the\\_Elements/](http://au.dir.yahoo.com/Science/Chemistry/Periodic_Table_of_the_Elements/)

[www.webelements.com/](http://www.webelements.com/)

[http://teachingtreasures.com.au/science-projects/periodic\\_table.htm](http://teachingtreasures.com.au/science-projects/periodic_table.htm)

[www.chemguide.co.uk/](http://www.chemguide.co.uk/)

[www.webelements.com/webelements/scholar/index.html](http://www.webelements.com/webelements/scholar/index.html)

<http://chemlab.pc.maricopa.edu/periodic/periodic.html>

[www.minerals.org.au/careers](http://www.minerals.org.au/careers)

[www.cas.com.au/pacia.htm](http://www.cas.com.au/pacia.htm)

**Molecular modelling**

[www.acdlabs.com/download/chemsk.html](http://www.acdlabs.com/download/chemsk.html)

**Virtual experiments**

[http://modelscience.com/udl\\_library.html](http://modelscience.com/udl_library.html)

<http://modelscience.com/products.html>

**Nanotechnology**

[www.flonnet.com/fl2210/fl221000.htm](http://www.flonnet.com/fl2210/fl221000.htm)

[www.sciencenewsforkids.org/articles/20040609/Feature1.asp](http://www.sciencenewsforkids.org/articles/20040609/Feature1.asp)

[www.sciencentral.com/articles/view.php3?article\\_id=218392126&language=english](http://www.sciencentral.com/articles/view.php3?article_id=218392126&language=english)

[www.physorg.com/](http://www.physorg.com/)

[www.nanotech-now.com/news.cgi?story\\_id=04149](http://www.nanotech-now.com/news.cgi?story_id=04149)

[www.azonano.com/news.asp?newsID=843](http://www.azonano.com/news.asp?newsID=843)

[www.azonano.com/news.asp?newsID=791](http://www.azonano.com/news.asp?newsID=791)

[www.chemistry.uq.edu.au/nbc/index.shtml](http://www.chemistry.uq.edu.au/nbc/index.shtml)

[www.csiro.au/index.asp?type=blank&id=Nanotechnology\\_About](http://www.csiro.au/index.asp?type=blank&id=Nanotechnology_About)

<http://modelscience.com/products.html>

[www.nanotechnology.com.au/frameset.htm](http://www.nanotechnology.com.au/frameset.htm)

<http://science.howstuffworks.com/nanotechnology.htm>

[www.foresight.org/NanoRev/index.html](http://www.foresight.org/NanoRev/index.html)

**Intelligent polymers**

[www.uow.edu.au/](http://www.uow.edu.au/)

**The atmosphere**

<http://vicozone.customer.net.net.au/#network>  
(ozone monitoring)

[www.epa.vic.gov.au/](http://www.epa.vic.gov.au/)

**Green chemistry**

[www.chem.monash.edu.au/green-chem/](http://www.chem.monash.edu.au/green-chem/)

[www.science.murdoch.edu.au/teaching/m234/recycle32.htm](http://www.science.murdoch.edu.au/teaching/m234/recycle32.htm)

[www.uyseg.org/greener\\_industry/](http://www.uyseg.org/greener_industry/)

[www.chem.leeds.ac.uk/People/CMR/nav.html](http://www.chem.leeds.ac.uk/People/CMR/nav.html)

[www.pprc.org/pubs/techreviews/co2/co2intro.html](http://www.pprc.org/pubs/techreviews/co2/co2intro.html)

[www.chemistry.org/portal/a/c/s/1/home.html](http://www.chemistry.org/portal/a/c/s/1/home.html)

[www.epa.gov/greenchemistry/principles.html](http://www.epa.gov/greenchemistry/principles.html)

**Supercritical CO<sub>2</sub>**

[www.uyseg.org/greener\\_industry/pages/superCO2/1superCO2\\_intro.htm](http://www.uyseg.org/greener_industry/pages/superCO2/1superCO2_intro.htm)  
[www.chem.leeds.ac.uk/People/CMR/moreco2.html](http://www.chem.leeds.ac.uk/People/CMR/moreco2.html)  
[www.chem.leeds.ac.uk/People/CMR/nav.html](http://www.chem.leeds.ac.uk/People/CMR/nav.html)  
[www.pprc.org/pubs/techreviews/co2/co2intro.html](http://www.pprc.org/pubs/techreviews/co2/co2intro.html)  
[www.chemheritage.org/EducationalServices/FACES/poly/readings/superco2.htm](http://www.chemheritage.org/EducationalServices/FACES/poly/readings/superco2.htm)

**DNA and forensic science**

<http://science.uniserve.edu.au/school/curric/stage6/chem/forchem.html>  
[www.nifs.com.au/FactFiles/DNA/how.asp?page=how](http://www.nifs.com.au/FactFiles/DNA/how.asp?page=how)  
<http://hsc.csu.edu.au/chemistry/options/forensic/2772/ch994.htm>  
<http://hsc.csu.edu.au/chemistry/options/forensic/2771/ch991.htm>

**Proteins as markers for disease**

[www.proteomesystems.com/home/profile.asp?MenuID=39&RefMenuID=21&TopMenuID=26&LeftMenuID=37](http://www.proteomesystems.com/home/profile.asp?MenuID=39&RefMenuID=21&TopMenuID=26&LeftMenuID=37)  
[www.biotechnologydirectory.com.au/companies/gu.htm](http://www.biotechnologydirectory.com.au/companies/gu.htm)  
[www.med.monash.edu.au/biochem/research/projects/neurobiology.html](http://www.med.monash.edu.au/biochem/research/projects/neurobiology.html)  
[www.science.org.au/nova/078/078key.htm](http://www.science.org.au/nova/078/078key.htm)  
[www.dpi.qld.gov.au/aquaculturenews/13564.html](http://www.dpi.qld.gov.au/aquaculturenews/13564.html)  
[www.bmsf.unsw.edu.au/research/collaboration/collabHiMW.html](http://www.bmsf.unsw.edu.au/research/collaboration/collabHiMW.html)

**Biochemical fuels**

[www.sustainable.energy.sa.gov.au/pages/advisory/renewables/types/biomass/biomass.htm:sectID=21&templD=52](http://www.sustainable.energy.sa.gov.au/pages/advisory/renewables/types/biomass/biomass.htm:sectID=21&templD=52)

**Design and synthesis of new medicines**

[www.csu.edu.au/learning/eubios/NBBDM.html](http://www.csu.edu.au/learning/eubios/NBBDM.html)  
[www.ebroadcast.com.au/dir/Business/Biotechnology\\_and\\_Pharmaceuticals/](http://www.ebroadcast.com.au/dir/Business/Biotechnology_and_Pharmaceuticals/)  
[www.chemistry-react.org/go/Tutorial/Tutorial\\_21681.html](http://www.chemistry-react.org/go/Tutorial/Tutorial_21681.html) (Aspirin)  
[www.gu.edu.au/centre/glycomics/staff/mvonitzstein.html](http://www.gu.edu.au/centre/glycomics/staff/mvonitzstein.html)  
<http://biosyn.com/organic/default.htm>

**Spectroscopy**

<http://scienceofspectroscopy.info/wiki/>  
<http://webbook.nist.gov/chemistry>  
<http://scienceofspectroscopy.info/wiki/>  
<http://webbook.nist.gov/chemistry> (NIST Chemistry webbook)  
[www.chem.uic.edu/web1/OCOL-II/WIN/SPEC/MS/Frames.HTM](http://www.chem.uic.edu/web1/OCOL-II/WIN/SPEC/MS/Frames.HTM)

[www.chem.uic.edu/web1/OCOL-II/WIN/SPEC/IR/Frames.HTM](http://www.chem.uic.edu/web1/OCOL-II/WIN/SPEC/IR/Frames.HTM)

[www.chem.uic.edu/web1/OCOL-II/WIN/SPEC/HNMR/Frames.HTM](http://www.chem.uic.edu/web1/OCOL-II/WIN/SPEC/HNMR/Frames.HTM)

[www.rod.beavon.clara.net/nmr1.htm](http://www.rod.beavon.clara.net/nmr1.htm)

[www.rod.beavon.clara.net/nmr4.htm](http://www.rod.beavon.clara.net/nmr4.htm)

[www.chemistry-react.org/go/default/Test/OnlineTest\\_42.html;jsessionid=ai4BckrcJGBc](http://www.chemistry-react.org/go/default/Test/OnlineTest_42.html;jsessionid=ai4BckrcJGBc)

**Chemistry of wine**

[www.chemistry-react.org/go/default/Tutorial/Tutorial\\_4783.html](http://www.chemistry-react.org/go/default/Tutorial/Tutorial_4783.html)

**Fuel cells**

[www.fuelcells.org.au/](http://www.fuelcells.org.au/)  
Fuel Cell Institute of Australia

**Risk Assessment (including information about chemicals)**

[www.chemistry-react.org/go/default/Tutorial/Tutorial\\_4955.html](http://www.chemistry-react.org/go/default/Tutorial/Tutorial_4955.html)  
[http://hermes.erin.gov.au/pls/cig\\_public/!CIGPPUBLIC.pStart](http://hermes.erin.gov.au/pls/cig_public/!CIGPPUBLIC.pStart)  
<http://chemdat.merck.de/mda/au/index.html>

**Victorian Essential Learning Standards (VELS)**

<http://vels.vcaa.vic.edu.au/support/teaching.html>

**General**

[www.science.org.au/events/npc2005.htm](http://www.science.org.au/events/npc2005.htm)  
Transcripts of key note speeches from Australia Academy of Science  
[www.chemsoc.org/timeline/pages/timeline.html](http://www.chemsoc.org/timeline/pages/timeline.html)  
History of Science time line

**Chemistry diagrams**

[www.btinternet.com/~chemistry.diagrams/index.htm](http://www.btinternet.com/~chemistry.diagrams/index.htm)

**Chemistry courses**

A level  
[www.chemistry-react.org/go/default/Default\\_100001.html](http://www.chemistry-react.org/go/default/Default_100001.html)  
Nuffield  
[www.chemistry-react.org](http://www.chemistry-react.org)  
Salters Chemistry  
[www.york.ac.uk/org/seg/salters/chemistry/](http://www.york.ac.uk/org/seg/salters/chemistry/)  
[www.chemguide.co.uk/index.html#top](http://www.chemguide.co.uk/index.html#top)

**Significant figures**

[www.chem.sc.edu/faculty/morgan/resources/sigfigs/index.html](http://www.chem.sc.edu/faculty/morgan/resources/sigfigs/index.html)  
[www.rod.beavon.clara.net/err\\_exp.htm](http://www.rod.beavon.clara.net/err_exp.htm)  
[www.chemistry-react.org/go/default/Tutorial/Tutorial\\_4428.html](http://www.chemistry-react.org/go/default/Tutorial/Tutorial_4428.html)

**ORGANISATIONS**

American Chemical Society  
[www.chemistry.org/portal/a/c/s/1/home.html](http://www.chemistry.org/portal/a/c/s/1/home.html)

Australian Science Teachers Association  
[www.asta.edu.au/home](http://www.asta.edu.au/home)

Chemistry Education Association  
[www.cea.asn.au/Frontpage/](http://www.cea.asn.au/Frontpage/)

CSIRO  
Bag 10  
Clayton South, Vic 3169  
Tel: 1300 363 400  
Website: [www.csiro.au/](http://www.csiro.au/)

Department of Innovation, Industry and Regional  
Development  
GPO Box 4509 RR  
Melbourne, Vic 3000  
Tel: (03) 9651 9999  
Website: [www.iird.vic.gov.au/CORPLIVE.262474/HOMEPAGE/  
502315602/HOME.html](http://www.iird.vic.gov.au/CORPLIVE.262474/HOMEPAGE/502315602/HOME.html)

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21 Vale Street  
North Melbourne, Vic 3051  
Tel: (03) 9328 2033  
Fax: (03) 9328 2670  
Email: [member@raci.org.au](mailto:member@raci.org.au),  
Website: [www.raci.org.au/](http://www.raci.org.au/)

The Royal Australian Chemical Institute  
Chemical Education Division  
School of Biological and Chemical Sciences  
Deakin University  
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